A BIOLOGICAL INVESTIGATION OF THE LEESTON DRAIN, CANTERBURY, NEW ZEALAND.

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by

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1 INTRODUCTION

Biological investigations of water pollution have been carried out in many overseas countries and a large body of information has now been collected. These contributions represent an integral part of water pollution assessment. In contrast, relatively little biological monitoring of water pollution has been carried out in New Zealand, and most of the studies which have been made here are short term surveys. These are represented by the studies of Bennington (1971), Cameron (1970), Fowles (1971), Hirsch (1958), Lear (1972), Marshall (1971), McCammon (1972) and Winterbourn _et al_. (1971). An exception to this is the work of Gibbs and Penny (1973) on the Wainui-o-mata River, in which monitoring had been carried out for over a year. The results of these biological studies have yet to gain full acceptance as a valid form of pollution monitoring compared to chemical studies. This lack of acceptance is unfortunate as exclusively chemical or biological approaches to pollution monitoring usually have shortcomings, but in combination often provide a realistic assessment of a situation.

Chemical methods, although able to determine the nature of pollution, rarely assess the biological effects of pollution whereas, biological measurements, though not generally capable of determining the specific pollutants involved, can show the integrated effects of pollution over a period of time and the extent of the pollution can often be determined.

In 1969, the Ellesmere County Council put forward a proposal to build a sewerage treatment plant at Leeston, the effluent from which would be discharged directly into the Leeston drain. The Leeston drain is mildly polluted by organic wastes originating from the septic tanks of the Leeston township, and in addition, dairy farmers release milking wastes into its lower reaches. As a result of litigation by the North Canterbury Acclimatization Society discharging of sewerage wastes will be restricted to autumn and winter and then only when land surrounding the treatment works can not absorb the irrigated effluent. It was felt by the Acclimatization Society that a more satisfactory solution would have been possible if information had been available on the effects of effluent discharge on the ecology of the drain which flows into Lake Ellesmere, an important wildlife refuge. As the discharge rights come up for renewal in two years time (1976) the present study was commissioned to produce biological information on the state of the drain and base line data for making future comparisons.

A further aim of this thesis was to examine in detail some aspects of the biology of the Oligochaeta, a group of considerable importance in polluted waters but one which in New Zealand has not received attention commensurate with its significance.

The primary aim of the present study was therefore to examine the physical and chemical characteristics of the Leeston drain and to evaluate their effects on the biota.

SECTION A

A BENTHIC FIELD STUDY

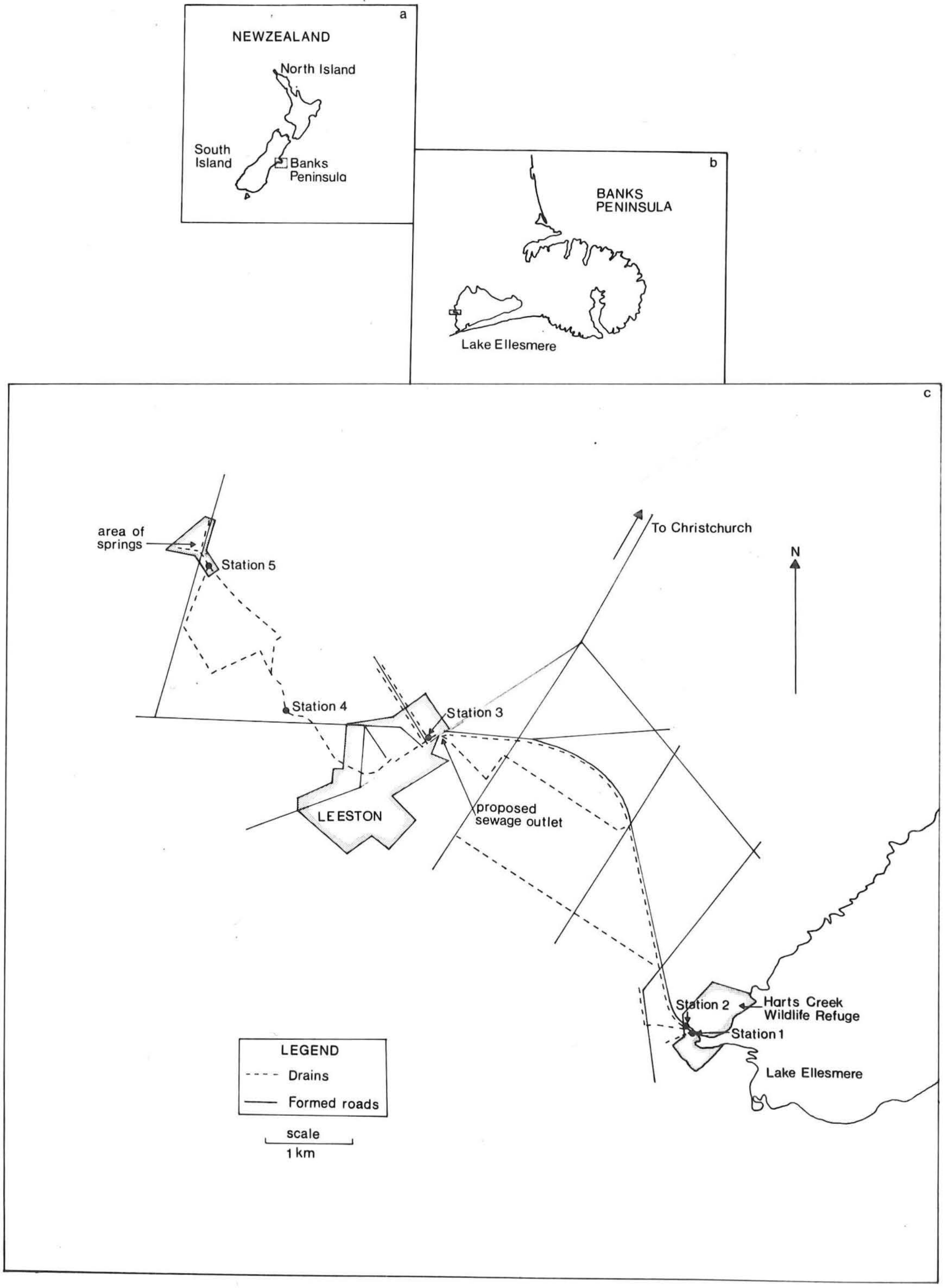
2 STUDY AREA

2.1 The Drainage Pattern

The Leeston drain is a free-running stream located 56 km north-east of Christchurch (Figure 1). It begins as rheocrene and helocrene springs in the peat lands of Killinchy, flows south-east over an impermeable clay band and cuts down into the underlying fluvial shingles. These shingles are overlain by fine silts and clays on which the agriculture of the district is based. The stream is 10 km long and falls 30 m between its origin and Lake Ellesmere (Figure 1). This fall is maintained by annual stream cleaning which exposes the fluvial shingles for most of the stream's length and produces a flow channel 0.5 m to 2 m deep. At its source the stream is 0.6 m wide and 0.2 m deep with a mean flow of 0.27 m/s. The dimensions of the stream increase to a width of 3.5 m and a depth of 0.5 m at the lower end of the Harts Creek wild life refuge (Figure 1). The moderating influence of Lake Ellesmere is apparent at this point where the water banks up and slows to 0.22 m/s.

For the first 3 km the stream drains lightly populated farmland and then flows into the Leeston township where it is mainly confined to open roadside drains. After the stream leaves Leeston it branches, one branch flowing through mixed crop and livestock farm land and the other continuing down an artificial drain adjacent to Tramway Reserve Road. The two streams coalesce 2.5 km further downstream and flow

FIGURE 1: Location of sampling stations and major features of the Leeston drain.


a
NEWZEALAND
North Island
South Island
Banks Peninsula
b
BANKS PENINSULA
Lake Ellesmere
c
area of springs
Station 5
To Christchurch
N
Station 4
Station 3
LEESTON
proposed sewage outlet
Station 2
Harts Creek Wildlife Refuge
Station 1
Lake Ellesmere
LEGEND
Drains
Formed roads
scale
1 km

along the artificial channel for another 2 km at which point another small stream (0.4 m wide x 0.1 m deep) runs into the channel. The combined waters then flow through the Lake Road culvert and into the wild life refuge where the stream becomes deeper and wider because of ground water seepage around the foundations of the culvert. A number of helocrene springs in this area also contribute to the increased stream discharge. One of the tributaries carries cow-shed waste from a dairy unit into the main stream. Along the final 150 m the stream flows through bog and swamp channels into the lake.

In late summer a large section of the artificial channel between the Leeston township and the confluence of the two streams dries up while the other branch maintains its flow. The overall stream system has a stable flow during summer because of its spring source, and because of the limited catchment (Figure 1) heavy flows are not produced during the winter. Exceptionally high rainfall in the winter of 1973 resulted in occasional spates.

Alterations to the drainage pattern: The study area was once swampy but with increased land use and drainage the water table has dropped and some of the original source springs have dried up. According to Dalmer (1970) the maintained lake level has also dropped.

The stream was originally converted to a drain but as the ground water level dropped it was used as a source of irrigation water and received wastes from the Leeston township and farms adjacent to the drain. Subsequently aquatic weed growth has become a nuisance and annual cleaning of the stream is essential to keep it clear. This was carried out in the late summer of 1972 by mechanical dragline and by hand cutting and raking operations. The dragline removed rooted macrophytes and a small amount of the stream bed which was dumped on to the banks. The remaining sediment was badly disturbed and a layer of mud settled out on the shingle surface. The substrate of the hand-cleaned sections around the Leeston township was undisturbed when the weeds were sheared off.

2.2 Sampling Sites and Descriptions of Stations

The aim of this study was to evaluate the existing biological condition of the stream and to provide a basis for future monitoring programmes. The positions of the stations selected therefore had to reflect the present situation and have potential as sites for testing and future changes.

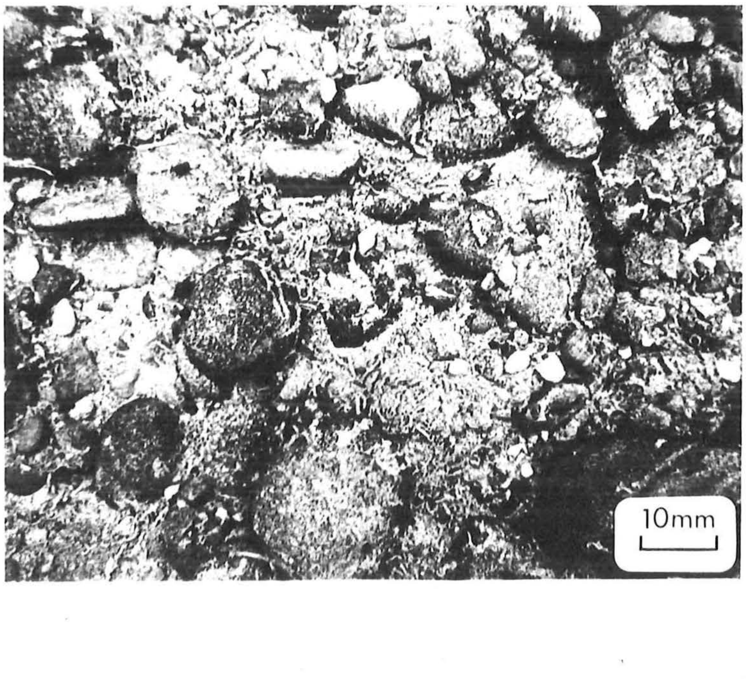
Station 1 (Plate 1): This station was 50 m downstream from the dairy shed outlet and was nearest to Lake Ellesmere. The substrate in the stream was exposed pebbles and unstable fine sands. Silt and organic material had accumulated on the surface, and the larger more stable pebbles were coated with epiphytic algae.

Macrophytic vegetation in the stream bed was confined to isolated patches of *Potamogeton pectinatus*. On the banks and extending into the water were clumps of *Nasturtium microphyllum* and *Mentha* spp. *Mimulus guttatus*, *Polygonum* sp. and *Agrostis stolonifer* were common on the banks and following removal during the weed cleaning operations they quickly regenerated.

PLATE 1: Location of Station 1 (top) and detailed section of stream sediment (bottom).

Scale (top plate): 1 division on scale ruler equals 0.1 m.

(Photos: J.W. Marshall).


10mm

Station 2 (Plate 2): Station 2 was the control station for Station 1 and also provided data on an unpolluted section. It was located 25 m upstream from the dairy outlet and 75 m upstream from Station 1. The substrate here lacked the finer sands present at Station 1 and the overall appearance was of a coarse surface gravel with small amounts of finer sediments in the interstices. A thin layer of algae coated the gravel and patches of *Potamogeton cheesmanii*, *Callitriche stagnalis* and a species of *Polygonum* grew in the consolidated substrate. On the banks and along the margins of the stream, but not in the stream itself, grew *M. guttatus*, *Ranunculus rivularis*, *R. fluitans*, *N. microphyllum*, *A. stolonifer*, *Cotula* sp. and a species of *Juncus*.

Station 3 (Plate 3): The third station was sited adjacent to the main road 95 m downstream from Leeston and 20 m upstream from the outlet pipe of the proposed sewerage farm. This station was chosen for three reasons:-

1 It gave a measure of the existing pollution from the township.

2 Any future alteration to the conditions of the stream as a result of the sewerage reticulation programme could be assessed as the nutrient status of the stream water passing this station should be reduced.

3 The effect of any future discharges from the sewerage works could be evaluated from this station because preliminary studies showed that the area below the proposed sewerage outlet pipe was similar to Station 3.

PLATE 2: Location of Station 2 (top) and detailed section of stream sediment.

Scale (top plate): 1 division on scale ruler equals 0.1 m.

(photos: J.W. Marshall).

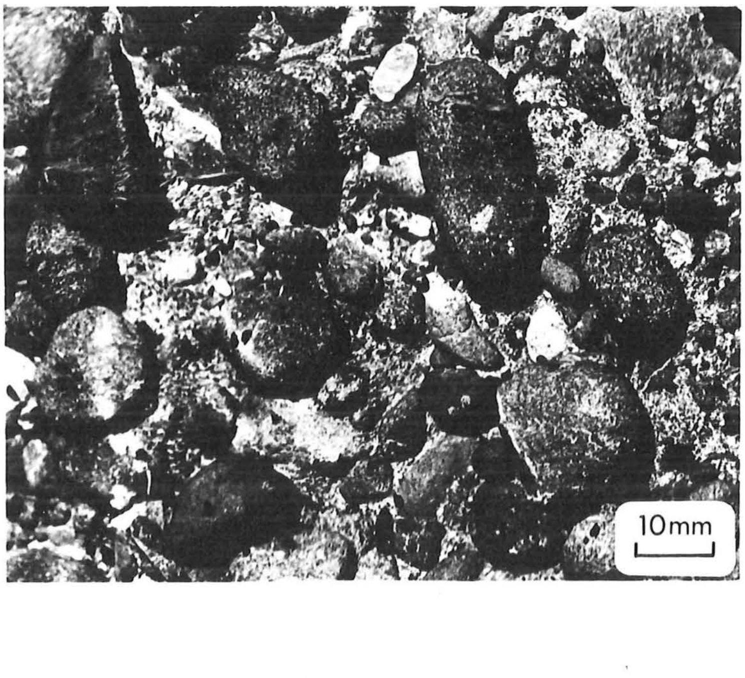

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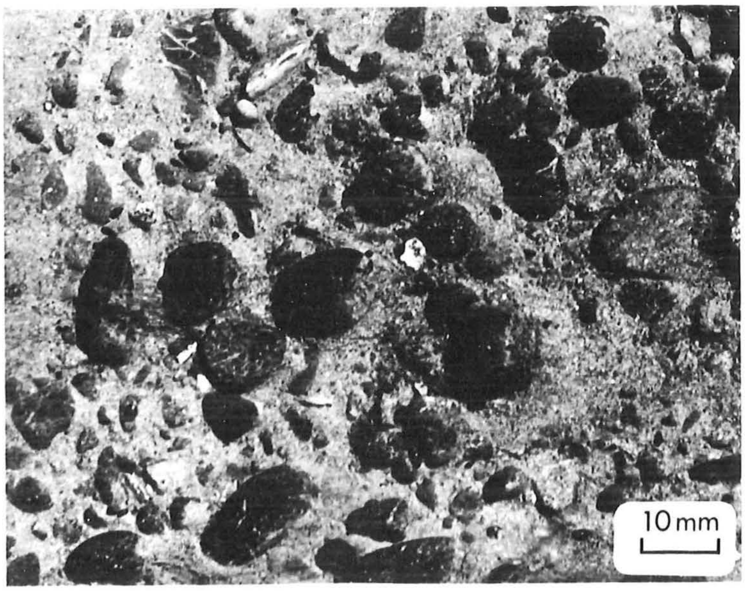
PLATE 3: Location of Station 3 (top) and detailed section of stream sediment (bottom).

Scale (top plate): 1 division on scale ruler equals 0.1 m.

(photos: J.W. Marshall).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The substrate of Station 3 consisted of the same basic material as the preceding stations but a greater amount of fine sand and mud was present on the surface and this partially obscured the pebbles. During the summer a thick layer of algae grew on the exposed shingle and large mats of filamentous algae grew on the macrophytes. Macrophytes present were *Elodea canadensis*, *Myriophyllum propinquum*, *P. cheesmanii*, *P. pectinatus* and *C. stagnalis*. In slower water *Lemna minor* and *Azolla rubra* proliferated. *Nasturtium microphyllum* was the dominant edgeplant and was associated with *Mentha* spp., *Ranunculus macropus* and *A. stolonifera*. During the summers of 1972 and 1973 these plants, particularly *N. microphyllum*, grew rapidly and almost clogged the stream.

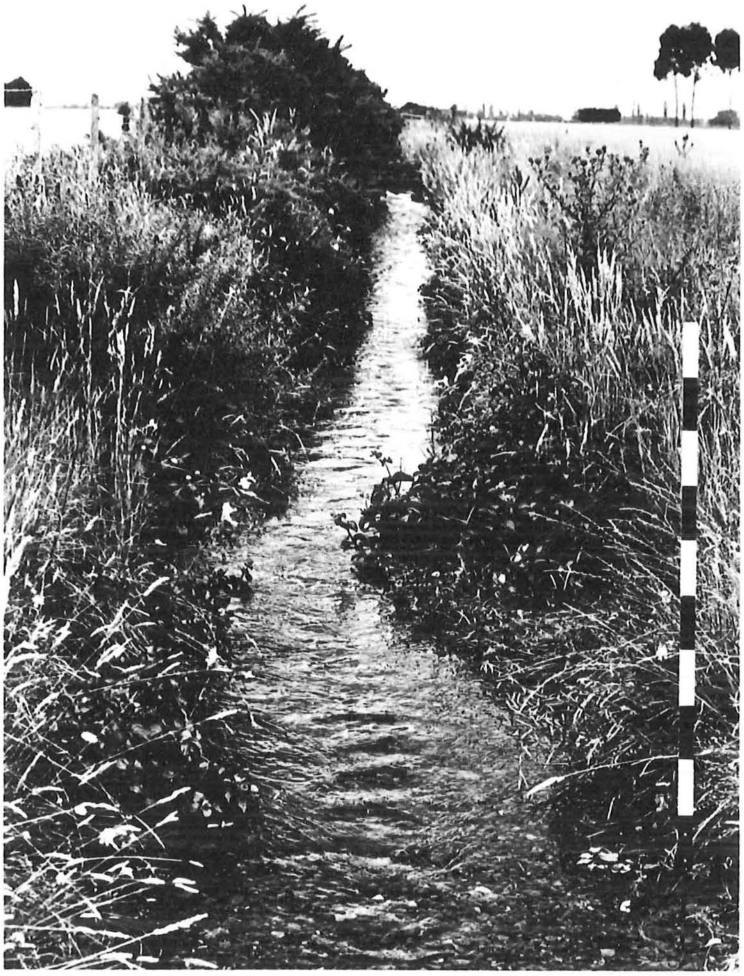
Station 4 (Plate 4): This station was 1.8 km upstream from Station 3 and was in a part of the stream that ran through arable farmland. The stream bed was similar to the other stations except that it was produced by the erosion of a 0.20 m thick layer of shingle from a clay matrix. Small amounts of fine sand, silt and clay occurred in the sediment. The shingle had a fine coating of algae and there were small patches of *P. cheesmanii*, *E. canadensis* and a species of *Polygonum* in the stream. On the banks and intruding into the stream were growths of *N. microphyllum*, *A. stolonifera*, *M. guttatus*, *Polygonum* sp. and a *Cotula* sp.

Station 5 (Plate 5): Station 5 was immediately downstream from one of the accessible springs in the headwaters of the stream.

PLATE 4: Location of Station 4 (top) and detailed section of stream sediment (bottom).

Scale (top plate): 1 division on scale ruler equals 0.1 m.

(photos: J.W. Marshall).



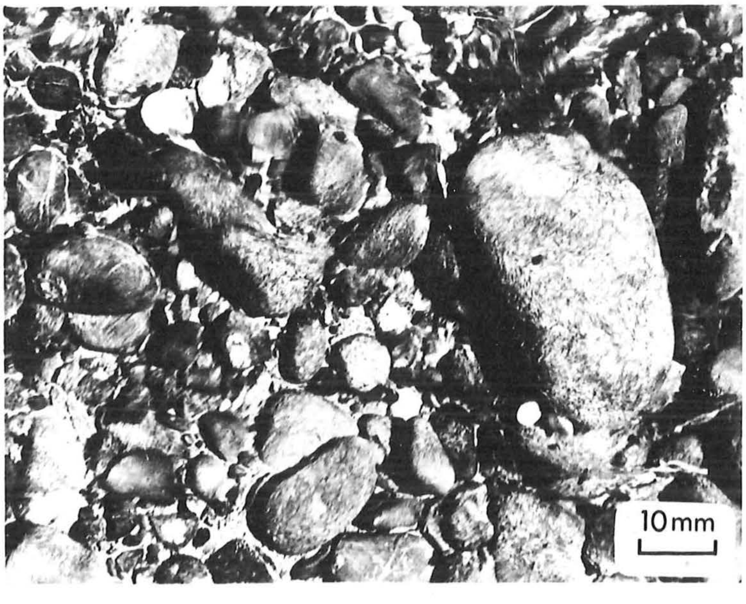

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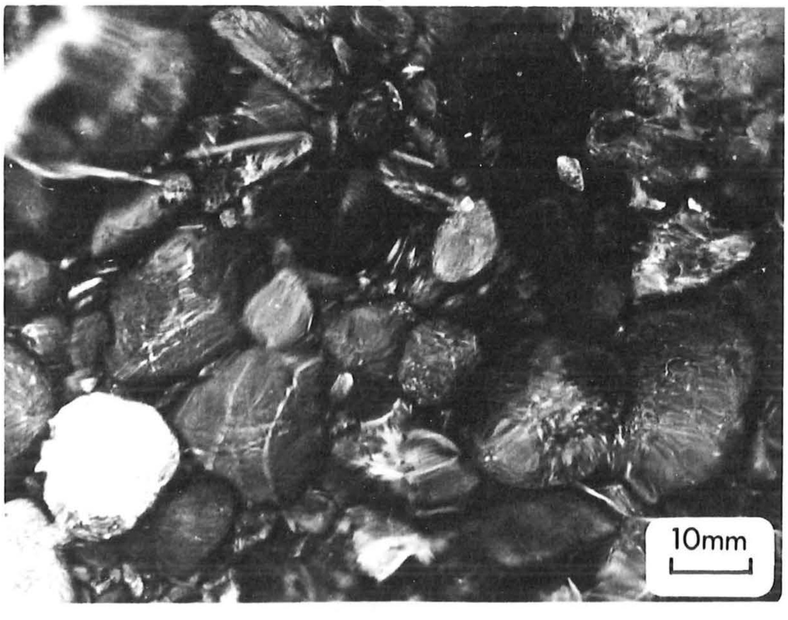
PLATE 5: Location of Station 5 (top) and detailed section of stream sediment (bottom).

Scale (top plate): 1 division on scale ruler equals 0.1 m.

(photos: J.W. Marshall).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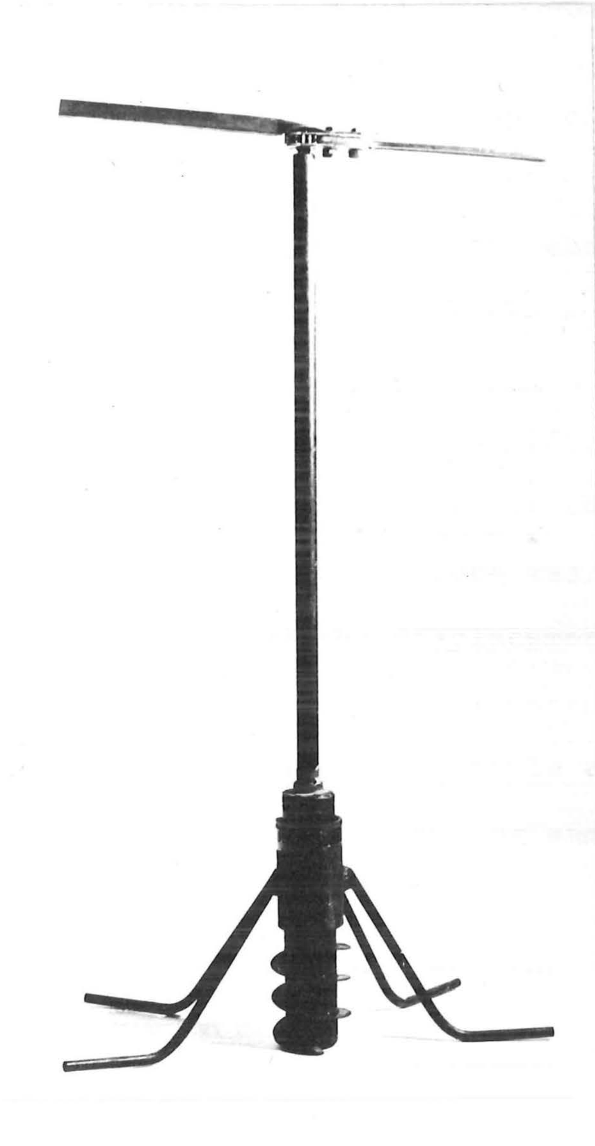
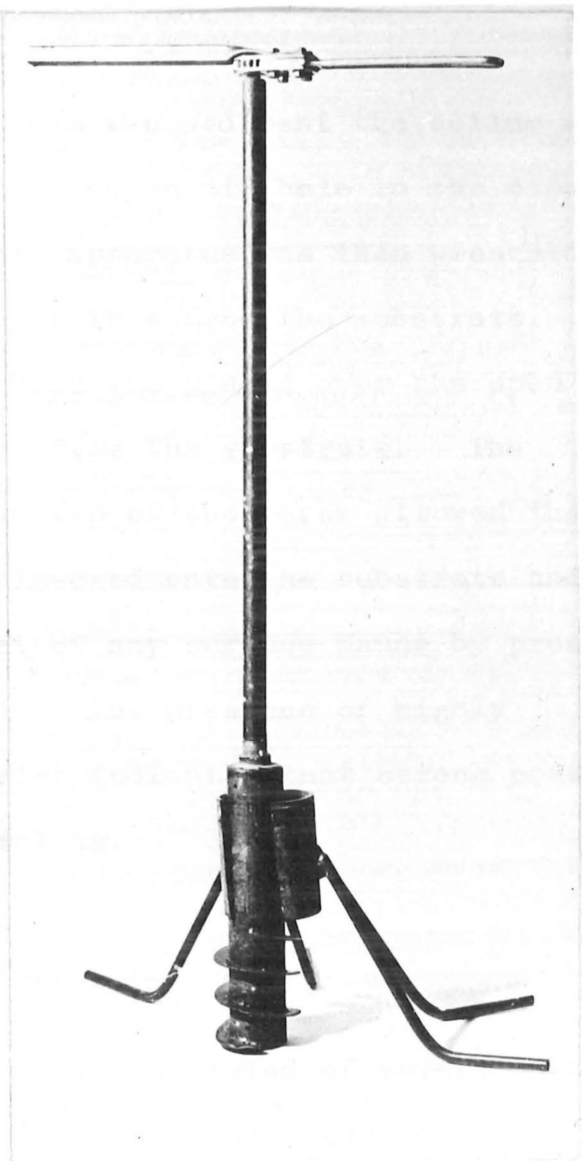
3 SAMPLING METHODS

3.1 Selection of Methods

A great deal has been written on the subject of benthic sampling devices and reviews have been written by Cummins (1962), Macan (1958), Southward (1968), Ulfstrand (1968) and Welch (1952). Cummins (1962) reviewed the efficiency of certain types of sampling devices with particular reference to lotic waters and concluded that core type samplers were often the most satisfactory quantitative samplers as they retain both sediment and animals for subsequent analyses. Although he advocated the use of core samplers, Cummins acknowledged that a completely satisfactory design had yet to be produced. In the present study a corer was used but problems were initially encountered because it could not be driven into the compacted substrate satisfactorily. These were solved by making modification to a simple cylinder corer (Plate 6). The modified corer was constructed of a cylinder of steel 0.3 m long and 60 mm in diameter capped with a staunchon plate welded over one end. Threaded into this plate was a solid 25 mm diameter steel shaft 0.6 m long with a ratchet driving handle mounted on the end of the shaft. Welded around the outside of this cylinder was a helix 1 mm thick of rectangular cross section and with an outstand of 15 mm. The helix had a pitch of 35 mm and spiralled down the cylinder to the open end of the cylinder. The end of the helix was reinforced with a tooth of 3 mm thick steel plate.

PLATE 6: Sediment corer with locating collar in position (left) and locating collar open (right).

(photos: J.W. Marshall).

When rotated in the sediment the helix bit into the sediment and pulled the corer into the substrate. As there was a tendency for the corer to rotate around the tip of the helix a locating collar was placed around the corer after it had been lowered on to the sediment to counteract this movement.

To extract the sampler from the sediment the collar was removed and a finger was placed over an air hole in the capped end of the cylinder. The whole apparatus was then wrenched on to its side to break the screw free from the substrate. As a precautionary measure, a hand was placed over the open end when the sampler was lifted from the substrate. The presence of the air hole at the top of the corer allowed the air to escape as the core was lowered onto the substrate and thus prevented the displacement of any surface fauna by pressure waves as the corer was lowered. The presence of highly mobile animals in the sample also indicated that strong pressure waves did not occur during sampling.

3.2 Selection of Sampling Positions

The bed of the Leeston drain consisted of several substrate types but exposed shingle substrates predominated. There were some changes in the composition of the sediments from site to site but the basic shingle, sand, silt and clay components persisted throughout the length of the stream.

Exposed shingle substrates were selected for study because:-

1 They represented the original and most abundant stream bed type and sampling of this sediment was

imperative for the establishment of a base line from which to make comparisons.

2 Reducing the variability of substrate types facilitated comparisons between stations.

3 It was easier to obtain quantitative samples from sediments than from macrophyte or algal growths.

This type of sampling programme in which a particular substrate type is selected for sampling to the exclusion of all others has been classified as a stratified random sampling approach but in the present study a comparison was carried out between 'strata' (Elliott 1971) of different stations and not different strata within the same station. Randomness of samples within stations was ensured by roughly plotting a grid along the stream bank and across the stream bed at right angles. Pairs of numbers were selected from a table of random numbers (Rolf and Sokal 1969) and used as the coordinates of the grid. Any sites so selected that had weed on their surfaces were discarded and replaced by selecting a new set of coordinates.

3.3 Size and Number of Samples

Elliott (1971) has pointed out that small samples are more satisfactory than large samples because:-

1 A number of small samples take as much effort to process as one large sample.

2 A number of small samples is of more statistical value than a few large samples.

3 Small samples cover a wider range of habitats than a few large samples and increase the likelihood of representative catches.

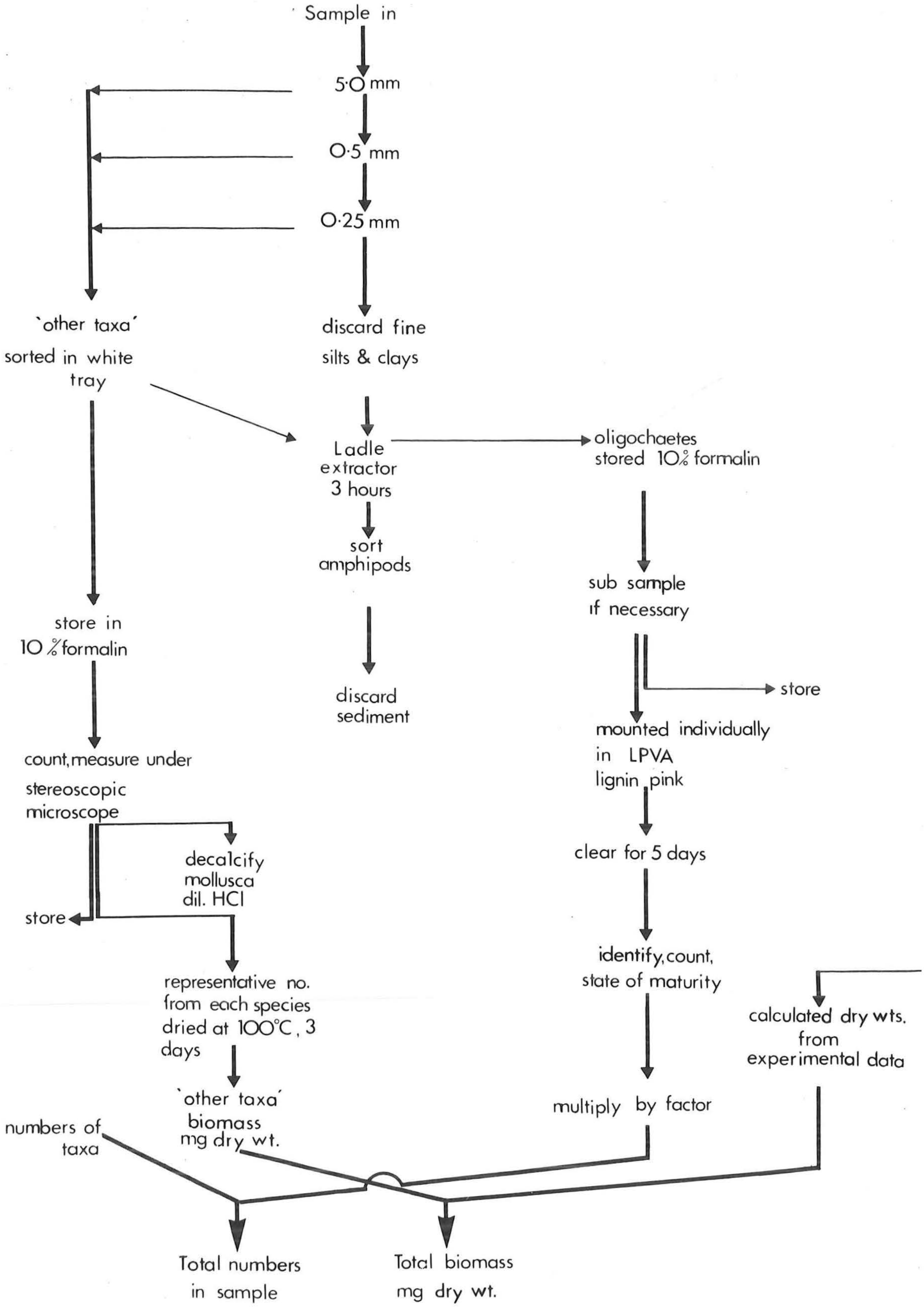
The actual size of the samples was determined by the upper mean size of the sediment and the nearest size of tubing available for construction of the sampler to encompass this size. Five replicate samples were taken at each station on each occasion for faunal analyses. This represented a compromise between optimum statistical reliability and the practicality of processing the samples.

3.4 Sampling and Sorting Procedures

Six cores were taken at each site to a depth of 150 mm and the resulting samples were stored in one pound "Agee" jars prior to processing in the laboratory. Sample processing steps are summarised in Figure 2. Five samples were washed by gently flowing water through a series of conical sieves with mesh sizes of 50 mm, 0.5 mm, and 0.25 mm. Jonasson (1955) considered that a satisfactory mesh size for retaining animals was 0.6 mm but the present study showed that a 0.25 mm mesh was necessary to retain small oligochaetes. The sixth sample was retained for sediment analysis.

The use of conical shaped sieves was found to be better than flat "Endecott" types as the sediment and animals could be concentrated at the apex of the cone. This also helped slow down the water flow, and the accumulation of water in the sieves reduced the possibility of damage to animals by direct water pressure. This was an important factor for the success of a subsequent heat extraction method. After any mud had been washed out, the remaining sediment was placed in a white sorting tray and all animals except oligochaetes and amphipods

FIGURE 2: Summary of sampling processing steps used in the study.


Sample in
5·0 mm
0·5 mm
0·25 mm
'other taxa' sorted in white tray
discard fine silts & clays
Ladle extractor 3 hours
oligochaetes stored 10% formalin
sort amphipods
sub sample if necessary
store in 10% formalin
discard sediment
store
mounted individually in LPVA lignin pink
count, measure under stereoscopic microscope
decalcify mollusca dil. HCl
clear for 5 days
store
identify, count, state of maturity
representative no. from each species dried at 100°C, 3 days
calculated dry wts. from experimental data
'other taxa' biomass mg dry wt.
multiply by factor
numbers of taxa
Total numbers in sample
Total biomass mg dry wt.

were extracted by hand. To improve picking accuracy and sorting speed a dilution method was used (Jonasson 1955; Marshall 1973).

The remaining sediment, containing oligochaetes and amphipods, from each sample was spread over 190 mm diameter discs of 0.5 mm brass mesh which were placed in a modified Berlese funnel (Ladle 1971). All living uninjured worms were extracted within three hours. The volume of water in the funnel was critical for optimal extraction efficiency and only sufficient water was used to produce capillary water movement in the sediment; higher levels parboiled the worms. Heat generated by the lights above the funnels killed all amphipods turning them pink, making them easy to see and remove after the worm extraction. All animals were preserved in 10% formalin. Animals other than oligochaetes were emptied into a gridded petri dish and identified, counted and divided into size groups under a stereoscopic microscope.

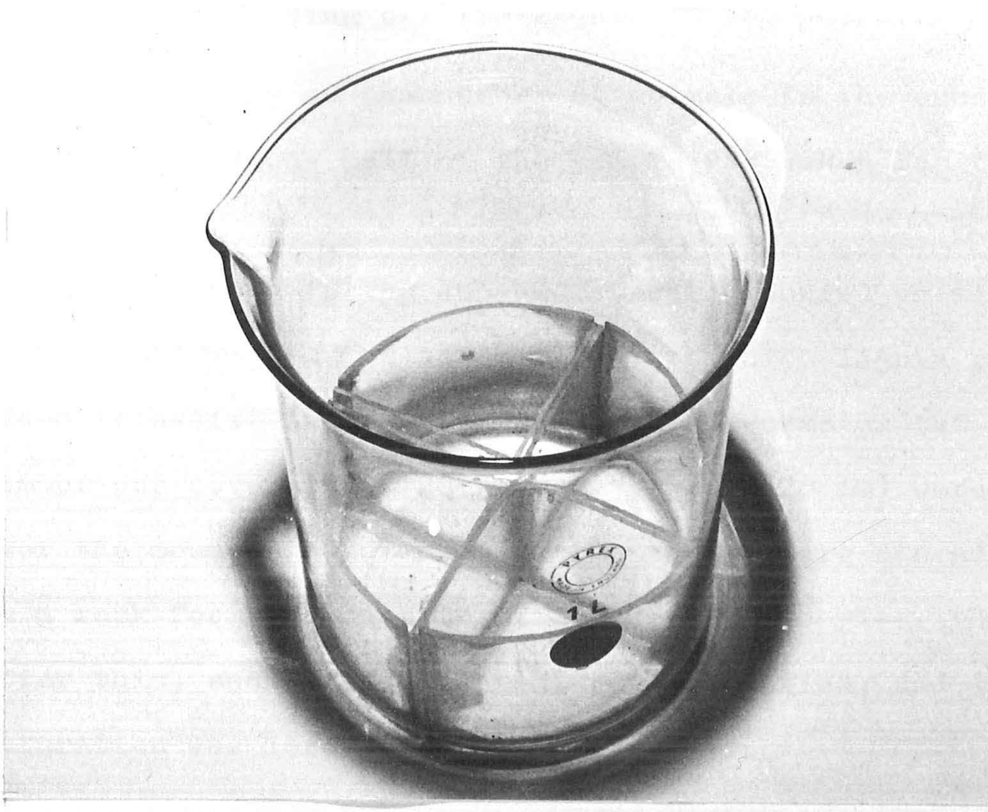
Treatment of oligochaetes was more detailed and where large numbers were present a subsample was taken using a modified tube sampler (Mundie 1971). It was necessary to modify Mundie's method because:-

1 The small cross sectional area of each vial resulted in many worms being caught on the lips of the vials

2 The placing of many small vials in the bottom of a beaker was too laborious and time consuming.
Instead a perspex cylindrical dish with 50 mm sides was constructed and fitted into the bottom of a one litre beaker (Plate 7). The dish was made up of four equal segments which could be removed

PLATE 7: Detailed view of segmented dishes used for subsampling (top) and segmented dishes positioned in a one litre beaker (bottom).

(photos: J.W. Marshall).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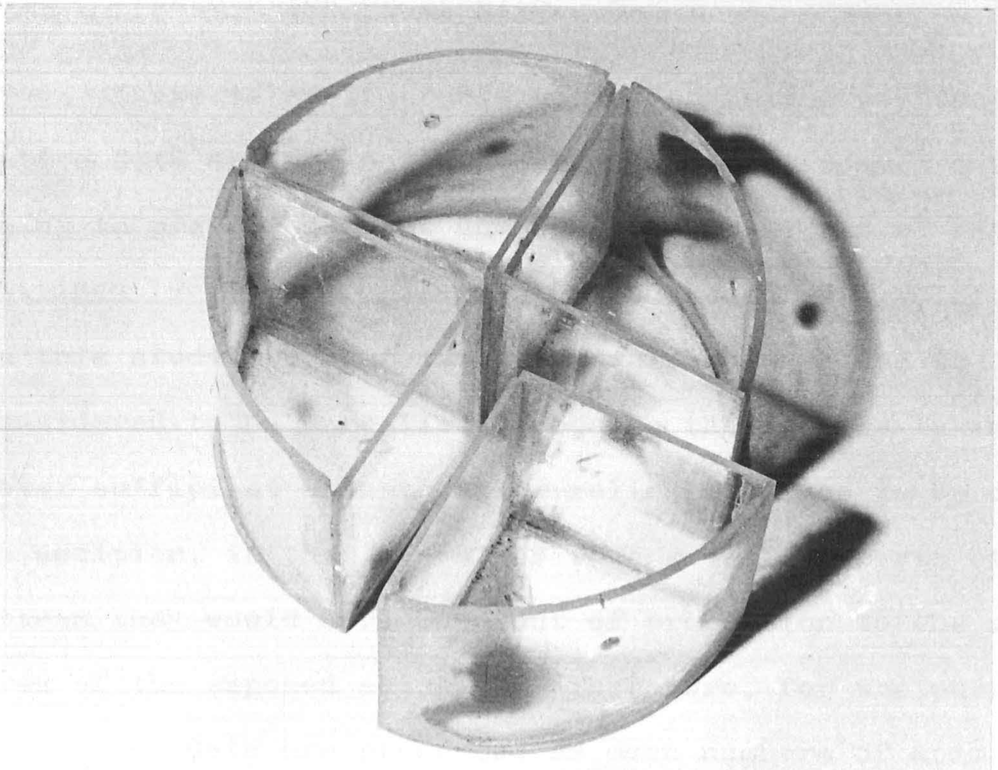


independently without the necessity of first siphoning off the liquid in the beaker.

Depending on the number of animals in the subsample one quarter to one half of the sample was taken for further study.

All worms in the subsamples were mounted on slides in lactophenol polyvinyl alcohol (LPVA) to which lignin pink was added to assist in locating the cleared worms on the slide. Number one coverslips (20 x 50 mm or 20 x 20 mm) were placed over the mounted specimens and the slides were stored on trays in a rack for five days to allow the LPVA to clear the worms. After this, each worm was examined, identified, and state of maturation was determined.

3.5 Presentation of Results

There is considerable variation in the way that quantitative data are presented; one of the most common methods being to present data as numbers of animals per m^2 (Harrel 1969; Maitland 1964; Radford and Hartland-Rowe 1971; Ulfstrand 1968). In this study, the expansion of small core values to $1m^2$ was considered to be unrealistic because the samples taken did not cover sufficient area to allow reliable values to be calculated. In addition, if the $1m^2$ values were given for parts of the stream they would have been out of proportion to the actual area of the exposed shingle. Therefore, for the purposes of this study data are presented as mean numbers of animals per 300 mm^2 sample. Standard errors of the five sample means varied considerably depending on species abundance, but in the case of the more common species eg. Tubifex tubifex and Potamopyrgus antipodarum it was approximately 20%, the value considered acceptable by Elliott (1971).

The raw data, processed data and statistical information are lodged in the Science Library, University of Canterbury.

4 PHYSICAL AND CHEMICAL FEATURES OF THE DRAIN

4.1 Introduction

The intimate interactions which are found between water, sediment and biota made it desirable to examine all three parameters in this study. Water samples (two per station) were collected approximately every 21 days for analysis. All samples were collected between 10 00 and 13 00 hours and were taken as close to the stream bed as possible. Phosphate phosphorus, nitrate nitrogen, nitrite nitrogen, pH and conductivity measurements were performed by Mr D. Lucas (Ministry of Agriculture and Fisheries, Freshwater Section, Christchurch). Mr J. Robb (Zoology Department, University of Canterbury) determined the ammonia nitrogen values. Measurements of dissolved oxygen (percent saturation) and biochemical oxygen demand (B.O.D.), sodium, water temperature and current flow were made by the author.

4.2 Methods

Water temperature: The temperature of the water was measured with a centigrade mercury thermometer held approximately 10 mm above the stream bed.

Water flow: Because access to a "Gurley", Pygmy flowmeter was difficult, water flow measurements were only taken once in each season. The mean flow at each station was calculated from three measurements taken at three depths.

Stream discharge: Stream dimensions were taken concurrently with stream flow measurements and from these the cross sectional area and discharge were calculated.

pH: Measurements of pH were made in the laboratory using a Beckman electromat pH meter.

Dissolved oxygen and percent saturation: The oxygen content of water samples was measured using the method outlined by Golterman (1969). The level II titrimetric method was used because of the possible interference of organic material. Percentage saturation was calculated from the oxygen solubility table in the same book.

Biochemical oxygen demand (B.O.D.): The five day B.O.D. method outlined in Standard Methods (1960) was followed except that aerated artesian bore water was used for dilutions, and samples were not seeded. Test blanks of dilution water showed no appreciable reduction in dissolved oxygen after five days.

Specific conductivity: This was measured in the laboratory at 20°C on a Philips PR9500 conductivity meter.

Sodium: An E.E.L. flame photometer Mark II was used to measure sodium.

Phosphorus (PO_4-P): Phosphate phosphorus determinations were carried out as outlined by Strickland and Parsons (1965) and expressed as g/m^3 of PO_4-P.

Nitrogen (NO_3-N, NO_2-N, NH_3-N): Nitrate and nitrite nitrogen were determined by the copper cadmium column reduction method outlined by Strickland and Parsons (1965). Nitrate nitrogen was expressed as g/m^3 of NO_3-N and nitrite nitrogen as g/m^3 of

NO_2-N. Ammoniacal nitrogen was determined by distillation and nesslerization of the distillate which was measured calorimetrically and expressed as g/m^3 of NH_3-N.

4.3 Results

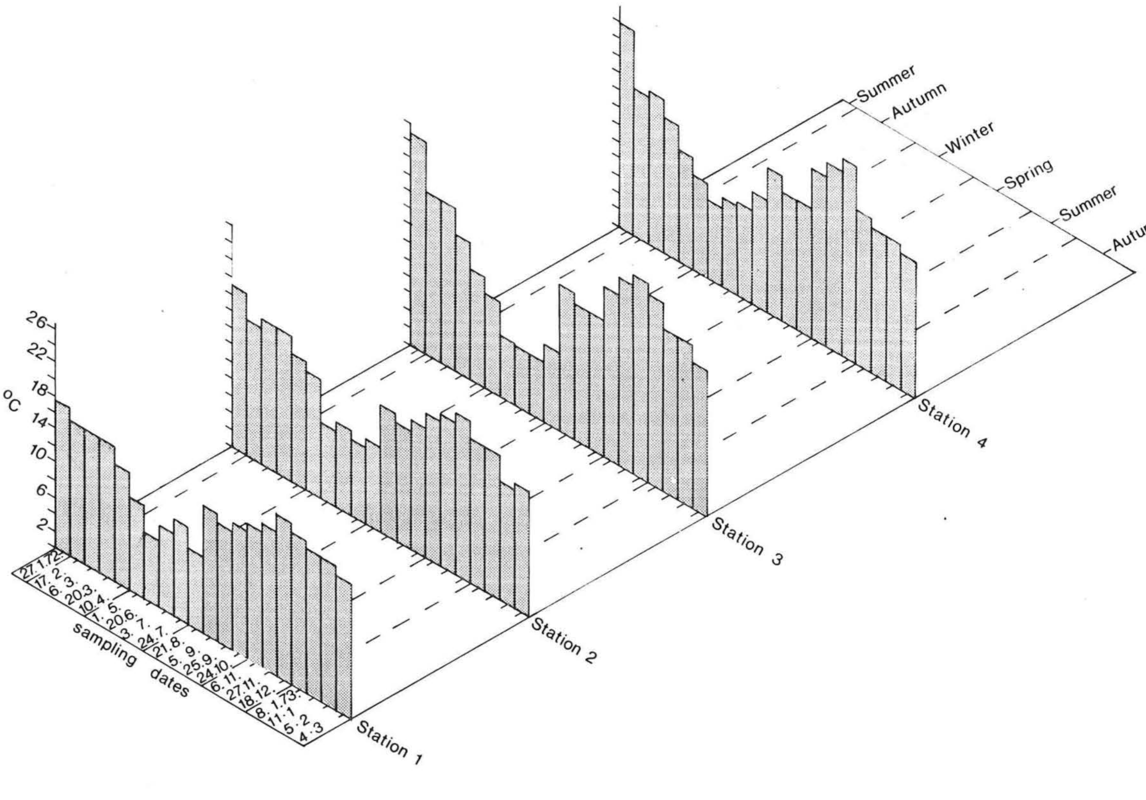
Water temperature: During the 15 month study period, temperatures ranged from 7°C in winter to 25°C in summer (Figure 3). Greatest seasonal fluctuations were found at Stations 3 and 4 which also had the highest mean annual temperatures (Table 1).

TABLE 1 : Mean annual water temperatures (°C) in the Leeston drain between January 1972 and March 1973.

Station	$\bar{X}$	Range
1	14.6	8.0 - 17.5
2	14.7	9.0 - 19.0
3	16.1	7.0 - 25.0
4	16.1	9.0 - 24.0

There was a rapid decline in water temperature from January to July when temperatures stabilised until mid August. Thereafter, water temperatures rose slowly reaching their maxima in early February. This seasonal cycle began to repeat itself in the following three months, but the temperature drop was not as rapid. There was a slight difference in temperatures recorded at different stations which may have been related to the difference in surface area to volume ratios of the stream. Thus, Stations 3 and 4 were shallower than the others and had the highest temperatures. The range of

FIGURE 3: Temperature (^{o}C) at four stations in the Leeston drain between January 1972 and March 1973.



26
22
18
14
10
6
2
°C
27.1.72.
17.2.
6.3.
20.3.
10.4.
1.5.
20.6.
3.7.
24.7.
21.8.
5.9.
25.9.
24.10.
6.11.
27.11.
18.12.
8.1.73.
11.1.
5.2.
4.3.
sampling dates
Station 1
Station 2
Station 3
Station 4
Summer
Autumn
Winter
Spring
Summer
Autumn

temperatures found was similar to those in other New Zealand streams studied (Allen 1951; Fowles 1972; Hopkins 1971).

Water flow: Mean flow values obtained at the five stations in four seasons are shown in Table 2.

TABLE 2 : Mean seasonal flow rate (m/s) in the Leeston drain.

Station	Summer	Autumn	Winter	Spring	Mean flow
1	0.19	0.20	0.21	0.29	0.22
2	0.24	0.28	0.29	0.38	0.29
3	0.10	0.09	0.12	0.20	0.12
4	0.28	0.30	0.29	0.37	0.31
5	0.26	0.26	0.28	0.29	0.27

The headwater springs maintained a continuous flow and much of the variation in flow between seasons reflected the pattern of water abstraction for irrigation. During the summer the presence of extensive weed beds also helped to reduce water movement. This was most evident below the Leeston township (Station 3) (Plate 8).

Stream discharge: The cross sectional area of the stream at each station was determined from width and depth measurements and the seasonal variations in discharge were calculated from these and flow measurements. Stations 3, 4 and 5 had similar discharges with maxima in spring (Table 3).

PLATE 8: Mid summer growth of <u>Nasturtium microphyllum</u> in the Leeston drain adjacent to Station 3.

(photo: J.W. Marshall).

TABLE 3: Mean seasonal cross sectional area (m^2) and discharge (m^3/s) at five stations in the Leeston drain.

	Summer		Autumn		Winter		Spring	
Station	Xs	Dis	Xs	Dis	Xs	Dis	Xs	Dis
1	0.710	0.134	0.730	0.146	1.510	0.317	1.850	0.565
2	0.360	0.086	0.360	0.100	0.510	0.147	0.540	0.250
3	0.048	0.005	0.058	0.005	0.084	0.010	0.091	0.018
4	0.020	0.005	0.022	0.006	0.042	0.012	0.045	0.016
5	0.020	0.005	0.021	0.005	0.041	0.011	0.041	0.012

Xs = Cross sectional area
Dis = Discharge

pH: The pH values obtained at all stations over 12 months are presented in Table 4.

TABLE 4: Mean annual pH and pH range at five stations in the Leeston drain.

Station	$\bar{X}$	Range
1	7.1	7.0 - 7.6
2	7.2	7.0 - 7.5
3	7.7	7.3 - 9.7
4	7.6	7.1 - 8.8
5	6.5	-

There were no well defined seasonal changes in pH except at Station 3 where marked increases in pH levels up to 9.7 were found during the summer of 1972. A heavy bloom of algae occurred at Station 3 at this time and very high levels of photosynthesis combined with low water levels probably produced the high pH values (Hemens and Mason 1968).

<u>Dissolved oxygen and percent saturation</u>: Results are presented in Figure 4. Oxygen concentrations were close to saturation levels at most times and occasionally were super-saturated. Clear seasonal fluctuations were found, highest saturation levels occurring in summer. Higher maximum values were found in summer 1972 than in summer 1973, in the former the water at most stations being super-saturated with oxygen probably as a result of rooted macrophyte photosynthesis in the stream bed. The contribution of the macrophytes to dissolved oxygen levels was shown by the sharp decrease to 65-70% saturation between the fourth and fifth months, soon after weed cleaning had been carried out.

During winter months the percent saturation at Stations 2 and 4 increased slightly and almost reached summer levels. These high levels could probably be attributed to blooming of algae at these stations. Algal blooms were not present at Stations 1 and 3, where percent saturation levels were lower. The disappearance of this algal mat coincided with the marked spring decline in percent saturation levels at Stations 2 and 4. The dissolved oxygen concentrations at Stations 1 and 3 increased to saturation in spring, but an inexplicable decline occurred at Station 3 during late spring. All stations were close to being 100 percent saturated with oxygen during the summer of 1973.

<u>Biochemical oxygen demand</u>: Results are presented in Figure 5. The B.O.D. levels at the four stations fluctuated around 3 g/m^3 throughout the year, although there was a tendency for higher values to occur in the early part of 1973. This

FIGURE 4: Percentage saturation of oxygen at four stations in the Leeston drain between January 1972 and January 1973.

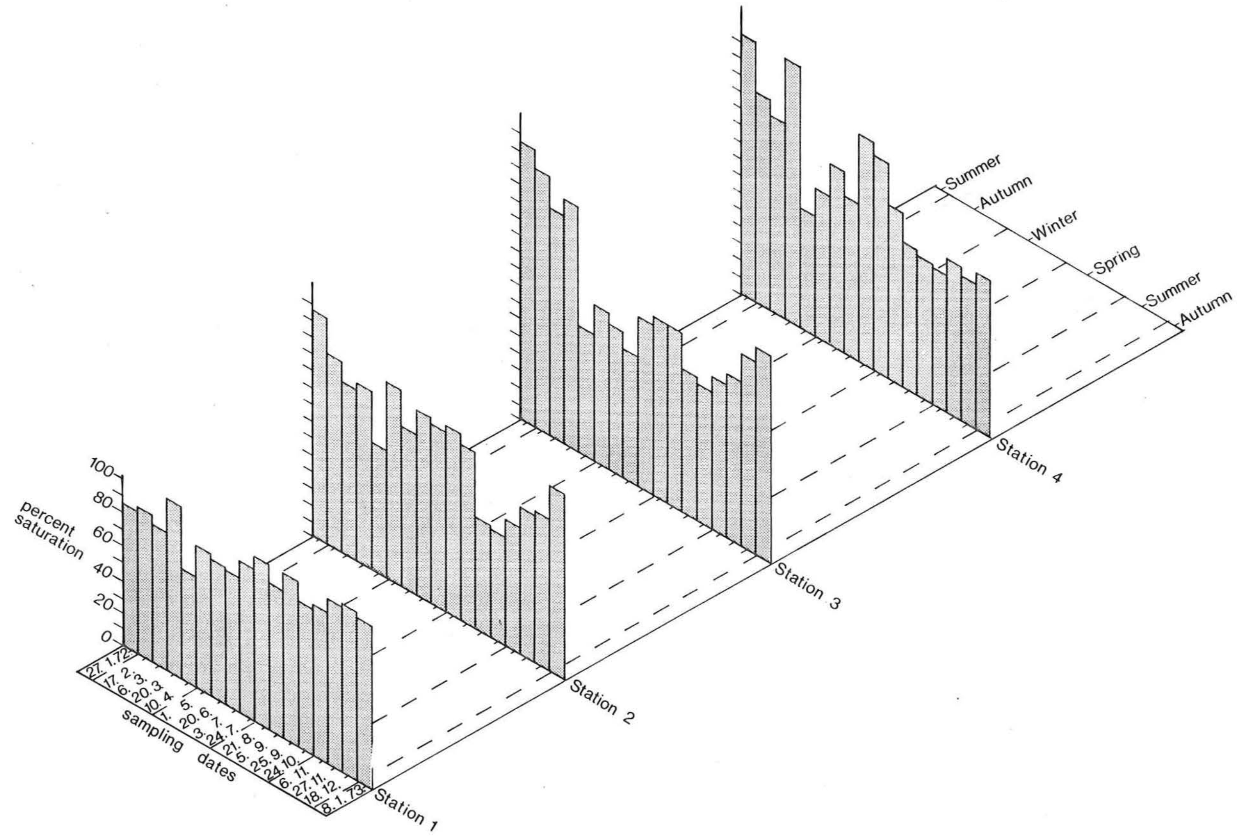
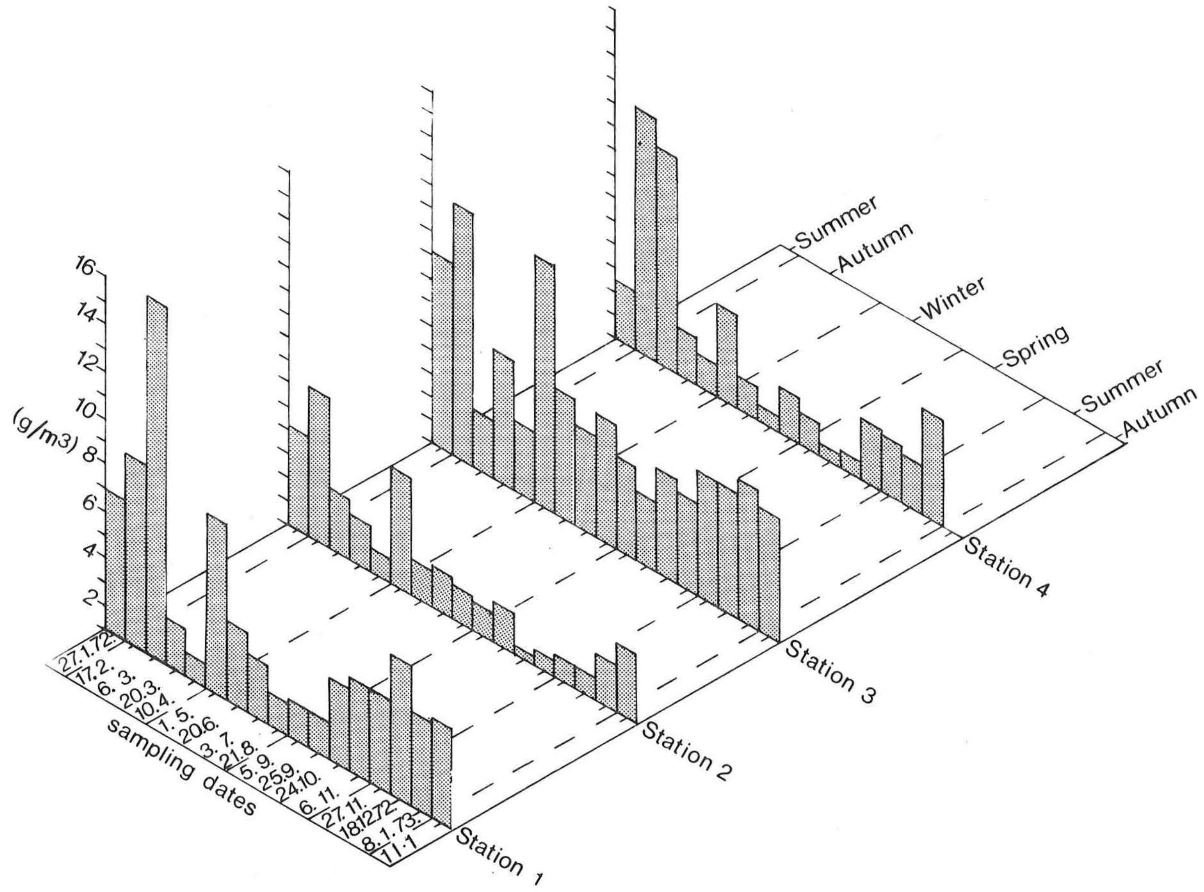

100
80
60
40
20
0
percent saturation
sampling dates
27.1.72
17.6.
20.3.
10.4.
2.3.
1.
5.
20.6.
7.7.
24.
21.8.
9.9.
25.9.
24.10.
11.
27.11.
18.12.
8.1.73
Station 1
Station 2
Station 3
Station 4
Summer
Autumn
Winter
Spring
Summer
Autumn

FIGURE 5: Biochemical oxygen demand values obtained at four stations in the Leeston drain between 27/1/72 and 11/1/73.


16
14
12
10
8
6
4
2
(g/m3)
27.1.72
17.2.
3.
6.
20.3.
10.4.
1.5.
20.6.
3.
7.
21.8.
6.
9.
25.9.
24.10.
6.11.
27.11.
18.12.72.
8.1.73.
11.1.
sampling dates
Station 1
Station 2
Station 3
Station 4
Summer
Autumn
Winter
Spring
Summer
Autumn

could have been caused by the concentrating effect of low water discharges, and conversely, the slight depression in B.O.D. levels during late winter and early spring could have been caused by dilution when discharge levels were higher. The highest B.O.D. values were obtained at Stations 1 and 3 (Table 5) which were sited downstream from known sources of effluent imput. According to the levels set by Thresh et al. (1958) Stations 2 and 4 could be considered clean, Station 1 fairly clean, and Station 3 doubtful.

TABLE 5 : Mean B.O.D. values (g/m^3) at four stations in the Leeston drain.

Station	$\bar{X}$	Range
1	4.2	1.0 - 15.2
2	1.9	0.4 - 6.4
3	5.1	2.8 - 10.8
4	2.6	0.6 - 10.4

Specific conductivity: Conductivity fluctuated at all four stations (Table 6) during the sampling period but these fluctuations did not show any clear relationship to other measured parameters.

TABLE 6 : Mean specific conductivities (μS) and range of values found in the Leeston drain.

Station	$\bar{X}$	Range
1	250	206 - 273
2	250	217 - 273
3	239	206 - 305
4	241	202 - 275
5	234	233 - 235

Little information on the significance of conductivity measurements in streams is found in the published literature but some results suggest that a number of generalizations can be made. Brink (1968) detected high conductivities of 950 to 1000 µS in the organically polluted section of a ditch, these values dropping to 650 µS as the ditch purified itself. Winterbourn <u>et al</u>. (1971) also found increased conductivity levels (260 µS) in organically polluted waters of the south branch of the Waimakariri River, levels declining to 80 µS further downstream. Minshall and Andrews (1973) and Young <u>et al</u>. (1971) observed reductions in conductivity with dilution of organically enriched waters.

The use of conductivity as a measure of slight organic pollution in the present study was not satisfactory as it could not detect the presence of diffuse effluent inputs against a relatively high background level of conductivity. By contrast, Young <u>et al</u>. (1972) and Winterbourn <u>et al</u>. (1971) were able to measure strong peaks up to 400 µS against a low background level of 80 µS water. In the present study the background level of conductivity was high (234 µS) as a result of the high ionic content of the spring waters and normal variations appear to mask any effects of pollution.

<u>Sodium</u>: Most of the effluents entering the Leeston drain are sewerage based and the presence of sodium chloride from urine (Klein 1962) and from detergents (Soltero 1969) would be expected in the water below such discharges. Water samples were collected during summer 1973 above, below and at Station 3, and their sodium content determined (Table 7).

TABLE 7: Mean sodium concentrations (meq/l) at three localities in the Leeston drain.

Station	$\bar{X}$	Range (3 samples)
Above Leeston township	21.0	19 - 23
Station 3	29.6	28 - 32
Below Station 3	25.6	25 - 26

Sodium levels were highest where pollution was known to be greatest and the preliminary results obtained suggested that measurement of sodium would provide a better measure of light organic pollution than conductivity in streams possessing water of high ionic content.

<u>Phosphorus</u>: Mean annual values varied between stations (Table 8) being highest at Stations 1 and 3 where organic effluent was known to be discharged.

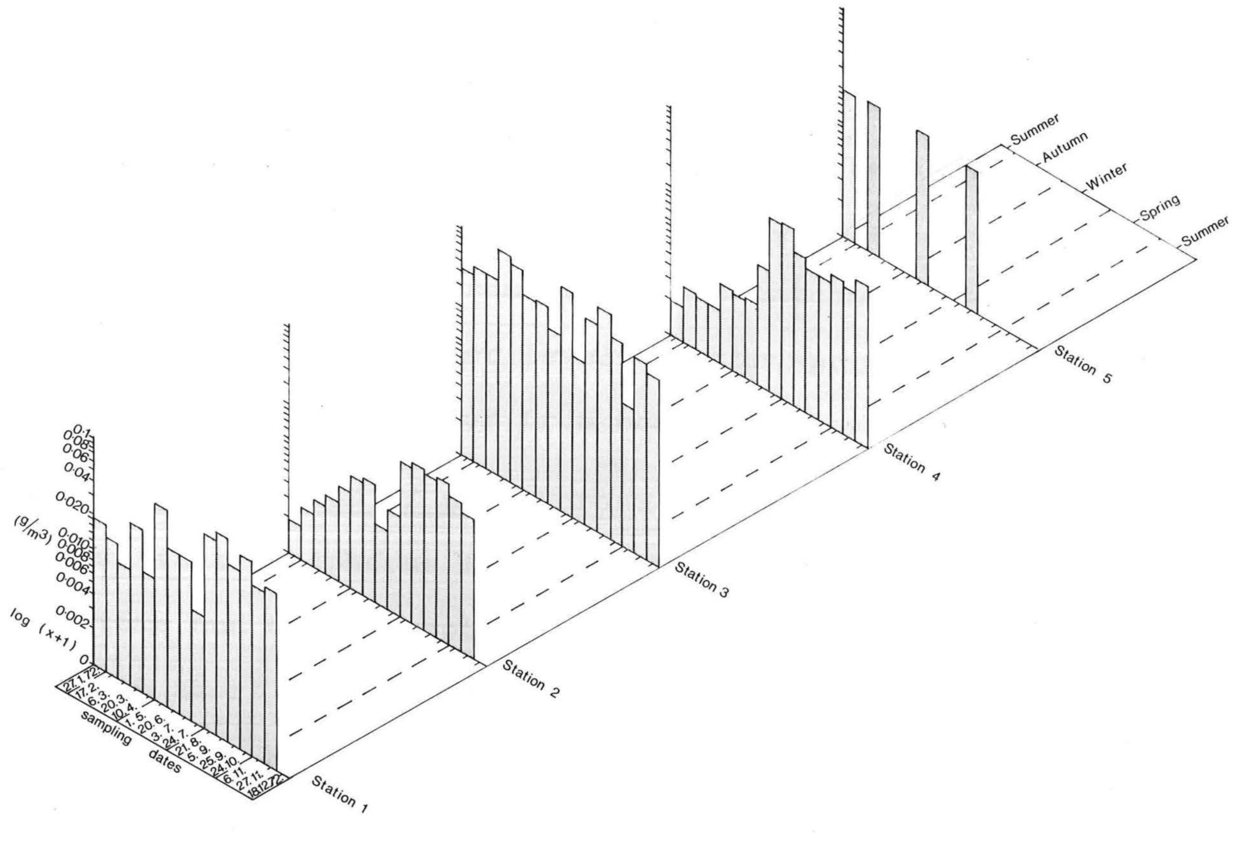
TABLE 8: Mean phosphate values (g/m^3) in the Leeston drain between January 1972 and December 1972.

Station	$\bar{X}$	Range	N
1	0.033	0.010 - 0.066	14
2	0.013	0.002 - 0.027	
3	0.055	0.019 - 0.120	
4	0.015	0.002 - 0.036	
5	0.021	0.020 - 0.022	4

The values obtained are not notably high and similar values have been detected in other streams in the Ellesmere district (Ministry of Agriculture and Fisheries, unpublished data). At Stations 2 and 4, PO_4-P levels were generally lower than at Stations 1 and 3 and concentrations were similar to those found by Gibbs and Penny (1973) in the upstream rural section of the Wainui-o-mata River, Wellington. In the polluted section of the Wainui-o-mata River, below a sewerage treatment plant outfall, they obtained levels of 0.041 - 0.33 g/m^3 which are far in excess of values obtained in the Leeston drain. In the feeder stream of the Morton Dam, Wellington, Vidal and Maris-McArthur (1973) detected PO_4-P values between 0.01 and 0.02 g/m^3 with a range of 0.005 - 0.07 gm/m^3.

Seasonal variations of phosphorus: During summer and autumn, PO_4-P levels at Stations 2 and 4 were at their lowest (Figure 6). This contrasts with the findings of Casey and Newton (1972) who found that increased water flow in winter and spring was associated with an increase rather than a decrease in PO_4-P. This increase in phosphate at Stations 2 and 4 in winter and spring was probably the result of surface run-off and an increase in the amount of re-suspended PO_4-P bearing particles present in the water during higher stream flow at that time. Surface run-off and re-suspension have been shown by Keup (1968), Smith (1959) and Sylvester (1961) to be significant contributors to the PO_4-P budgets of streams, the extent of such run-off being dependent on soil type, land use, vegetation cover and topography. As the Leeston drain flows through flat permanent pasture and arable land, surface drainage would probably be higher during winter when the land becomes almost waterlogged because of a naturally high water table (1.8 m below ground level according to the Ellesmere County sewerage reticulation map, 1968), and any additional rainfall would run off rapidly as found in Sweden by Brink (1968). The apparent insensitivity of PO_4-P levels to changes in stream discharge at Stations 1 and 3 (Figure 6) could

FIGURE 6: Phosphate phosphorus levels obtained at five stations in the Leeston drain between January 1972 and December 1972.


0·1
0·08
0·06
0·04
0·020
0·010
0·008
0·006
0·004
0·002
0
(g/m3)
log (x+1)
27.1.72.
17.2.
3.3.
6.
20.3.
10.4.
1.5.
20.6.
3.7.
24.7.
21.8.
5.9.
25.9.
24.10.
6.11.
27.11.
18.12.72.
sampling dates
Station 1
Station 2
Station 3
Station 4
Station 5
Summer
Autumn
Winter
Spring
Summer

have been caused by the relatively constant input of effluent bearing waters at these stations overshadowing minor changes caused by rainfall.

Spring water PO_4-P levels: The level of PO_4-P at Station 5 which was at the spring source was higher than in Stations 2 and 4 but within the range of PO_4-P levels found in springs elsewhere. Keup (1968) presented values of PO_4-P between 0.001 and 0.19 g/m^3 in Wisconsin and Maine springs. He also noted that many streams examined had PO_4-P levels below 0.02 g/m^3. Casey and Newton (1972) found PO_4-P levels between 0.01 and 0.08 g/m^3 at spring sources in the River Frome (England) catchment. They proposed that the higher levels in the springs were caused by seepage of fertilizer from commercial cress beds.

Assimilation of phosphorus: Several workers have shown that phosphorus is a highly mobile component in aquatic systems and can be rapidly absorbed, assimilated and re-cycled within short stretches of running water (Brink (1968); Bristow and Whitcombe (1971); Holden (1961); Jewell (1971); Johnson and Owen (1971); Keup (1968); McRoy *et al.* (1972); Pomeroy *et al.* (1969); Schwoerbel and Tillmanns (1964)).

Uptake rates within streams have been calculated by Keup (1968), who stated that uptake has a constant logarithmic rate which can be expressed by the symbol k. Calculation of k depends on the stretch of stream considered having a constant discharge, and only one section of the Leeston drain was suitable for the determination of uptake rate. This was the section between Stations 4 and 5, a distance of 2 km.

Rate of uptake was calculated from Keup's (1968) equation:

$$k = \frac{\log n \text{ Station } 5 - \log n \text{ Station } 4}{\text{distance}}$$

If uptake of PO_4-P occurs, k has a negative value. The percentage change in PO_4-P concentration was also calculated for this section of the stream. Because of seasonal variations in discharge, uptake of PO_4-P and percentage uptake were calculated separately for summer, autumn, winter and spring. During summer and autumn uptake (k) values of -1.034 and -0.848 were obtained. These represented a net uptake of 87% and 82% respectively within the 2 km section of stream. These high levels of uptake occurred in the period of maximum primary production and in addition to assimilating phosphorus the large amounts of aquatic weed present could have acted as a trap for suspended particulate material on which PO_4-P was adsorbed. After this section was cleared of weeds in late summer the rate of uptake declined (k = -0.012) and the percentage uptake was only 0.5%. This low uptake level was probably related to much lower primary production and increased stream flow which re-suspended sediment with a high phosphate content.

During spring there was a slight increase in the rate of uptake (k = -0.035) but the uptake was only 1%. Primary production increased at this time but because of high stream flow the presence of re-suspended material may have tended to mask the effect of this increased uptake by plants. This is suggested by the results of Brink's (1968) study in a small Swedish drain. He found that increased stream flow re-suspended large amounts (6 to 8 g/m^3) of phosphate bearing sediment which, during the previous summer and winter had been deposited in the stream. When stream flow declined a high uptake rate was re-established. Because of the diffuse nature of nutrient inputs to the stream in the Leeston township area it was not possible to directly measure the phosphate content of the inputs, but an attempt was made to calculate net input figures by extrapolating uptake rates from Stations 5 to 4, to the section between Stations 4 and 3. This approach was considered reasonable because of the comparable discharges and overall similarity of the two stream sections. The difference between the extrapolated and observed values obtained for Station 3 was taken as the net contribution of PO_4-P to the stream by Leeston township. Net PO_4-P varied seasonally and is shown in Table 9.

TABLE 9 : Net seasonal variations in PO_4-P inputs from the Leeston township.

	Summer	Autumn	Winter	Spring
uncorrected for differences in discharge (g/m^3)	0.069	0.049	0.035	0.058
discharge corrected values (g/hr)	1.08	0.72	1.44	3.6

The major inputs from the town are likely to be fairly constant (septic tank flushings) and seems likely that most of the seasonal differences found were due to variations in plant assimilation and stream discharge. When the PO_4-P values were corrected for differences in seasonal discharge rates (Table 9) it was found that the major increase in PO_4-P input occurred in the spring. Changes in discharge between Stations 2 and 3 because of the entry of drains and tributaries precluded the possibility of making uptake rate calculations in this section. Contributions of PO_4-P made by the dairy farm outlet were calculated from differences between the discharge corrected values for Stations 2 and 1, and are presented in Table 10.

TABLE 10: Seasonal contributions to stream PO_4-P from dairy outlet (discharge corrected values in g/hr).

Summer	Autumn	Winter	Spring
6.4	12.2	25.2	68.4

The increased amount of PO_4-P carried by the stream in spring in both the Leeston area and at the dairy outlet (Tables 9 and 10) suggests that stream flow at that time of year was shifting a greater amount of sediment and this capacity would have been enhanced by the lack of weed growth in the stream. The mean annual contribution of PO_4-P to the Leeston drain was greater from the dairy farm outlet (28.0 g/hr) than from the Leeston township area (1.7 g/hr).

<u>Nitrogen</u>: Mean annual NO_3-N levels in the Leeston drain showed a steady decline from 5.1 g/m^3 at Station 5 to 1.0 g/m^3 at Station 1. (Table 11).

TABLE 11: Mean annual and seasonal NO_3-N values (g/m^3) in the Leeston drain.

Station	Summer	Autumn	Winter	Spring	Mean
1.	0.577	0.550	1.58	1.27	1.00
2.	0.839	0.721	1.58	1.58	1.36
3.	3.350	2.852	4.01	4.01	3.30
4.	1.700	2.620	4.35	4.35	3.60
5.	4.200	4.510	6.00	6.00	4.95

Seasonal fluctuations were found between stations but the relative differences in levels between stations generally remained similar. Values obtained at Station 1 were unexpectedly low at the time of sampling, possibly because the milking shed wastes had been largely flushed past the sampling point so the values obtained could represent only the effluent residue. The increased discharge in this section would also have diluted the organic material as it entered the stream. Mean annual NO_2-N varied considerably between stations (Table 12), highest levels being recorded at Station 3.

TABLE 12: Mean NO_2-N and NH_3-N levels (g/m^3) in the Leeston drain.

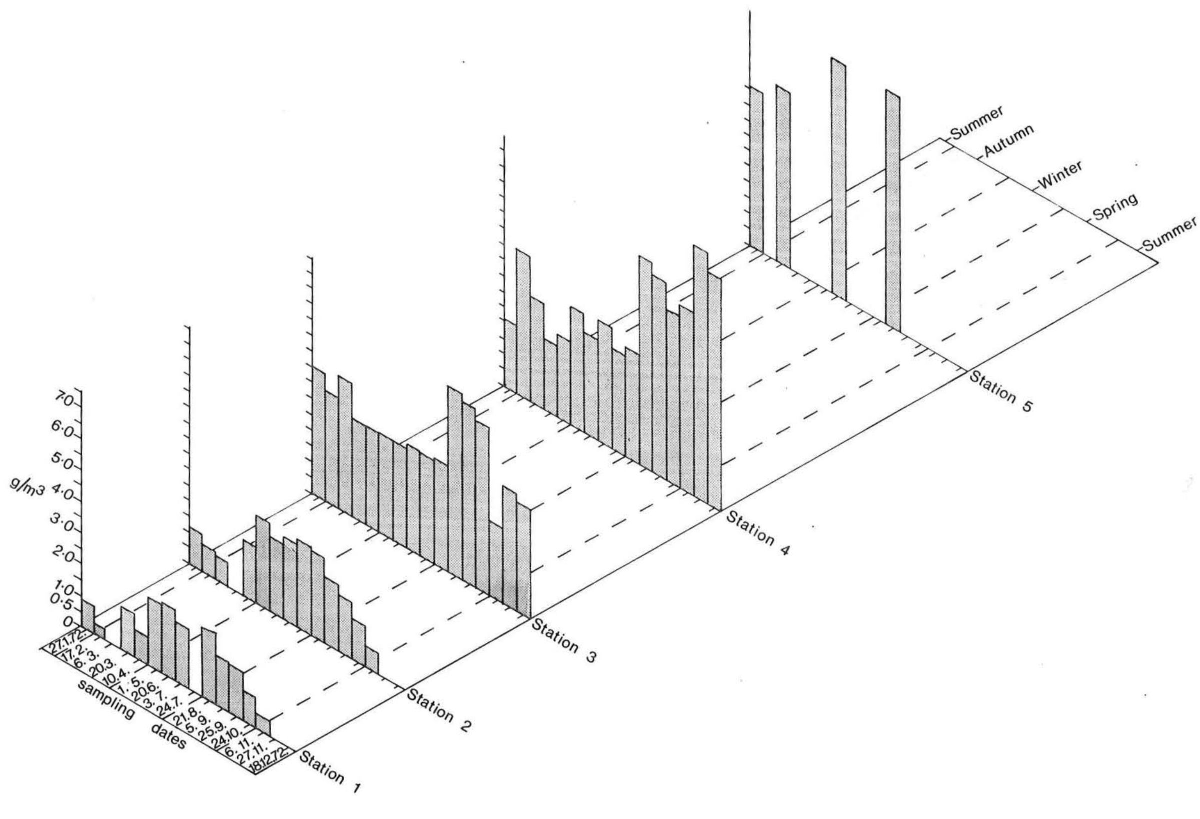
Stations	NO_2-N	NH_3-N
1.	0.013	0.20
2.	0.016	0.02
3.	0.070	0.12
4.	0.011	0.02
5.	trace	trace

An anomalous situation was found at Station 2 which had a higher mean level of NO_2-N than Station 1. However, ammonia analyses carried out in spring (6/11/72) showed that the highest levels occurred at Stations 1 and 3 (Table 12) paralleling the pattern of PO_4-P distribution. These results suggest another possible reason for the low level of NO_3-N at Station 1. As most of the material discharged into the stream at Station 1 came from milking sheds and was in a raw state it is likely that much of the nitrogen present would have occurred as NH_3-N and NO_2-N and there may not have been sufficient time for large amounts to be converted to NO_3-N by the time it reached the station.

Seasonal variations of nitrogen: Seasonal fluctuations of NO_3-N and NO_2-N were similar and in accord with PO_4-P fluctuations discussed previously. Lowest levels generally occurred during summer (Figure 7) but an exception was found at Station 3 where levels were similar in summer and spring. Some of the factors affecting seasonal variations in PO_4-P may also affect NO_3-N levels but because of the complex chemical interactions which occur between the different nitrogen species (Committee Report, 1970) other factors such as pH could affect the existence and conversion of NO_2-N and NH_3-N to NO_3-N (Hemens and Mason 1968).

Spring water NO_3-N levels: The mean level of NO_3-N in the spring station was higher ($4.95\ g/m^3$) than that in any other section of the stream (Table 11) and is in excess of most published nitrate levels (Casey and Newton 1972; Johnston 1972; Kingsford et al. 1970; Sawyer 1962). The NO_3-N

FIGURE 7: Nitrate nitrogen levels at five stations in the Leeston drain between January 1972 and December 1972.


g/m3
7·0
6·0
5·0
4·0
3·0
2·0
1·0
0·5
0
27.1.72.
17.2.
3.
17.
6.
20.3.
10.4.
1.
5.
20.6.
7.
3.
24.7.
21.8.
9.
5.
25.9.
24.10.
6.
11.
27.11.
18.12.72.
sampling dates
Station 1
Station 2
Station 3
Station 4
Station 5
Summer
Autumn
Winter
Spring
Summer

values found by Baber and Wilson (1972) for domestic ground water in the Waikato area were below 2.3 g/m^3 but they found some bore water in the same area had NO_3-N levels in excess of 15 g/m^3.

Nitrate levels in the spring water are below the maximum of 10 g/m^3 NO_3-N set by the World Health Organisation for drinking water. However, if a large quantity of nitrogen rich water was discharged into this basically high NO_3-N water there could be adverse affects on animals drinking it (Baber and Wilson 1972).

<u>Assimilation of nitrogen</u>: Levels and rates of uptake of NO_3-N were calculated between Stations 4 and 5 as for PO_4-P. Seasonal variations in uptake (Table 13) were observed but they were not as pronounced as those for PO_4-P.

TABLE 13: Seasonal uptake of NO_3-N in the section between Stations 4 and 5 of the Leeston drain.

	Summer	Autumn	Winter	Spring
Rate of uptake (k)	-0.450	-0.269	-0.316	-0.160
% uptake	59	42	46	27

Uptake rates were extrapolated back to Station 3 and the calculated net contributions of NO_3-N by the Leeston township in each season are presented in Table 14.

TABLE 14: Net contributions of NO_3-N to the Leeston drain by the Leeston township.

	Summer	Autumn	Winter	Spring
Uncorrected for differences in discharge (g/m^3)	2.43	1.10	0.81	0.56
Discharge (g/hr) corrected contribution	43.9	19.8	29.1	36.2

Values uncorrected for discharge were highest in summer but when they were corrected for stream discharge a high level of NO_3-N was found to occur in spring also (Table 14). It may be significant that the level of NO_2-N reflected this seasonal pattern (Table 15) and may indicate that factors other than plant growth and stream discharge influence seasonal NO_3-N patterns.

TABLE 15: Seasonal discharge corrected NO_2-N values (g/hr) at Station 3.

Summer	Autumn	Winter	Spring
2.8	2.16	3.6	21.6

Hemens and Mason (1968) have shown that the rate of oxidation by nitrifying bacteria increased during summer and decreased during winter, in a shallow outdoor experimental stream in South Africa. A similar mechanism may operate in the Leeston drain, in particular at Station 3, and could be responsible for the increased levels of NO_3-N and NO_2-N recorded in summer. Because of differences in discharge between Stations 1 and 2 the net nutrient input from the dairy farm was calculated from discharge corrected figures (Table 16).

TABLE 16: Seasonal discharge corrected NO_3-N values (g/hr) for dairy farm outlet.

Summer	Autumn	Winter	Spring
18	28.8	680	1418

High NO_3-N levels in spring and winter may be related to high stream discharge levels flushing accumulated NO_3-N from the sediments. By contrast in summer and autumn lower discharge levels and increased plant activity combine to remove NO_3-N from the water column. The lower levels of NO_3-N recorded below Leeston township compared with below the dairy outfall do not necessarily signify lower inputs from the town but rather probably indicate a higher level of removal, from the water by sedimentation and uptake by weeds in this part of the stream. There was little opportunity for processes other than floculation and sedimentation to operate in the vicinity of the dairy outlet.

PO_4-P : NO_3-N ratios: As high levels of NO_3-N occur naturally in the ground water of the Leeston drain (Station 5) the ratios of P to N were greater than those found in other New Zealand streams which have been examined (Table 17).

TABLE 17 : Mean annual ratio of PO_4-P to NO_3-N in the Leeston drain and other New Zealand streams.

Station		South Branch Waimakariri River	Horokiwi River
1	1:340	1:25	1:16
2	1:170	Fowles (1972)	Allen (1951)
3	1:520		
4	1:278		
5	1:234		

The addition of sewerage to stream waters increases its nutrient content (Brink 1968; Soltero 1969) and may alter the P:N ratio. This was apparently the case at Station 3 below the town (Table 17). Gibbs and Penny (1973) recorded a P:N ratio of almost 1:2 downstream from a sewerage treatment plant in the Wainui-o-mata River, Wellington, and Soltero (1969) found in the Gallatin River, U.S.A., that the ratio was 2:1 below a sewerage treatment plant through which large amounts of synthetic detergents passed with little degradation. Brink (1968) also noted that a reduction in the P:N ratios from 1:8 to 1:3 occurred as a result of synthetic detergents being present in sewerage water.

Although changes in P:N ratio in the Leeston drain were not as dramatic as in these studies, the lower ratio found below Leeston township can probably be attributed to heavy use of synthetic detergents in the area. At Station 1 the P:N ratio was also low but this was probably because of low levels of NO_3-N in the water rather than a heightened PO_4-P level. Davis (1973) has recorded P:N ratios of 1:2.8 for dairy shed wastes in New Zealand. Such effluent would be likely to increase the P:N ratio rather than decrease it.

4.4 Conclusion

The Leeston drain is mildly enriched in terms of N and P levels and in the vicinity of the Leeston township this has resulted in an aquatic weed problem and the presence of heavy growths of algae. Sphaerotilis occurred in the winter. Levels of phosphate were below the limits of 0.1 g/m^3 given for flowing waters and 0.05 g/m^3 for waters entering a lake above which biological nuisances occur (Mackenthun 1969) and suggest they may not have universal applicability. The level of NO_3-N above which biological nuisances can occur is stated by Mackenthun (1969) to be 0.3 g/m^3, and this was exceeded in the Leeston drain because of the naturally occurring high background levels.

Nutrients introduced from the Leeston township were removed from the stream waters within 4 km and excessive weed growth was not found below this point. Although the stream had the ability to remove nutrients in quantity, the ultimate fate of this assimilated material is uncertain. Weeds are cleared from the drain but most are left beside the bank and a high proportion of the nutrients contained in them must leach back into the stream. An exception is in the Leeston township where weeds are carted away after removal from the drain. Further nutrient is undoubtedly stored in the sediment of the stream bed. Sporadic spring spates re-suspend large amounts of this sediment and flush it downstream into Lake Ellesmere. Removal of the upper 30 mm of sediment during stream cleaning should considerably reduce the amount of material ultimately entering Lake Ellesmere. Dairy farm wastes high in nutrients discharged into the stream close to Lake Ellesmere have direct access to the lake, especially in times of high stream discharge.

5 THE SUBSTRATE

5.1 Introduction

The ecological importance of sediment particle size in running waters has been the subject of many investigations, the results of which have been ably reviewed by Cummins (1964, 1966) and Cummins and Lauff (1969). The lotic situation does not lend itself to easy analysis of sediments compared with the marine situation where sediments are usually well sorted and easy to collect (Jansson 1967; Saunders 1958, 1960; Wieser 1959). With a few exceptions (for example Wene 1940) studies in the lotic area are comparatively recent. The investigations of Cummins (1964), Scott (1958), Thorup (1966) and Ulfstrand (1967) have demonstrated that correlations exist between species distributions and sediment sizes, and experiments by Cummins (1964), Cummins and Lauff (1969), and Eriksen (1964, 1966) have been used to substantiate field observations.

Experimental work has also shown that in some cases the pore size between sediment particles is of considerable importance (Jansson 1967; Wieser 1959), as pore size influences the circulation of interstitial water and oxygen levels, and these in turn affect the distribution of benthic animals (Eriksen 1966). The effect on the benthic fauna of alterations to sediments by pollution has been considered by Chutter (1969), Hamilton (1961), Hynes (1963) and Nuttall (1972).

A detailed quantitative analysis of the sediment was carried out in the present study in conjunction with the regular faunal sampling programme.

5.2 Methods

The analytical procedures and sediment categories outlined by Cummins (1962) were used. During routine benthic sampling, a 150 mm core of substrate was taken from each station each month and analysed for size composition and organic content. Each sample was ellutriated through a 63 µm sieve and the ellutriant collected, evaporated to dryness and weighed. The larger fraction was also dried at 100°C for 48 hours and sieved by a machine shaker for 30 minutes through a graduated set of "Endecott" sieves. The sediment was separated into ten classes according to particle size (Table 18).

TABLE 18: Substrate particle size terminology and categories*.

Cummins Classification	Wentworth classification particle size range (mm)	phi Scale
Pebble	16 - 32	- 4
Gravel	7.9 - 16	- 33
	4.7 - 7.9	- 2
	2.0 - 4.7	- 1
Very coarse sand	1.0 - 2.0	0
Coarse sand	0.50 - 1.0	1
Medium sand	0.250 - 0.50	2
Fine sand	0.125 - 0.250	3
Very fine sand	0.6125 - 0.125	4
Silts and clay	<0.0625	5 - 9

*After Cummins (1962).

The different size fractions were weighed individually and fractions 1 mm and less were recombined for organic analysis. A subsample of the recombined sediment was obtained by splitting a coned sample and then it was ashed in a muffle furnace at 600°C for 30 minutes. This method was suitable for determining organic content as there were only small amounts of clay in the samples (Frey 1960). The duration of ashing was determined by extending the ashing period on a test sample until a constant weight was obtained. Hydrometric analysis of silts and clays was not necessary as only small amounts of these materials were present (Cummins 1962). Results of analyses of sediments at each station have been expressed as mean percent cumulative frequencies, and those for 12 selected samples are shown in Figure 8 using the Phi scale. The graphic mean, and measures of sorting, skewness and kurtosis, were determined according to Folk (1965).

5.3 Implications of Sediment Values to Lotic Situations

The significance of calculated sediment values has to be determined primarily in relation to sedimentary petrology and the ecological significance of these values in running waters has not been fully defined.

<u>Graphic mean</u>: The graphic mean is a measure of the general size of the material that has been deposited and gives an indication of the amount of energy of the original transporting medium, i.e. the current.

<u>Sorting</u>: Sorting is a more useful value as it gives a measure of homogeneity of the sediment. Sorting has a

pronounced effect on the interstitial pore size of the sediment and is affected by the size of material available and type of deposition. In fluvial deposition there is a tendency to 'dump and scour' as opposed to the situation in marine sediment deposits which are evenly spread by tidal action. Time also has a bearing on sorting efficiency and as fluvial action is generally fairly rapid, this associated with 'dump and scour' produces poorly sorted sediments.

Skewness: Skewness measures the asymmetry of the sorting curve. The direction of skew is dependent on the mean sediment size and is best considered in conjunction with kurtosis.

Kurtosis: Kurtosis is the most informative of all the measures as it tends to summarise all the other values and at the same time describes the regularity of sorting. Any changes in the sorting ratio are expressed as numerical values which represent different shaped curves. The limits and verbal description of these curves are set out in Table 19.

TABLE 19: Limits and verbal description of kurtosis values

- 0.4 to 0.9	Platykurtic
1.0	Mesokurtic
1.1 to ∞.	Leptokurtic

A platykurtic value indicates that the tails of the curve are better sorted than the centre whereas leptokurtic values are better sorted in the middle than at the tails. Platykurtic curves are generally associated with a bimodal distribution of sediment sizes which gives rise to a flattened curve. The presence of a platykurtic curve tends to indicate that the original traction load received an addition of a particular sediment size which subsequently altered the particle size composition. The leptokurtic condition is the opposite of this and indicates that parts of the normal sediment size distribution are missing.

5.4 Results

<u>Full core sediments</u>: The composition of the sediment at each station was similar in most months except after the stream was cleaned (10/4/72) when there was an increase in the percentage of silts and clays present at each station. The greatest increase occurred at Station 3 where the sediment was finest. The mean values in Table 20 and Figure 8 show that the composition of the sediment at the four stations was very similar.

TABLE 20: Mean cumulative percentage composition of sediments at four stations in the Leeston drain (17/2/72-8/1/73).

	Stations			
mm	1	2	3	4
16	28.1	33.3	26.5	36.6
7.9	53.4	61.2	49.6	64.6
4.7	63.3	72.2	60.9	74.6
2	72.7	77.6	68.7	80.2
1	77.0	80.7	74.6	84.9
0.500	77.9	82.7	81.4	87.7
0.250	90.4	91.6	91.5	93.3
0.105	96.1	97.5	97.3	97.0
0.063	97.5	98.3	98.2	97.8
<0.063	99.5	99.6	99.4	99.5
% organic	1.8	1.5	2.2	1.7

On the basis of graphic mean, sorting, skewness and kurtosis values (Table 21) all the sediments can be classified as sandy gravels, poorly sorted with a strong coarse skew which indicates that they all have the same origin (Folk 1965). The degree of kurtosis shows the extent of alteration to the original sediments. Stations 1 and 3 were platykurtic, Station 2 was mesokurtic and Station 4 was leptokurtic.

TABLE 21: Graphic mean, sorting, skewness and kurtosis of the sediment at four stations.

		Stations			
		1	2	3	4
Graphic mean		2.0	2.2	1.9	2.6
Sorting	Ø	2.6	2.6	2.5	2.2
Skewness		0.6	0.6	0.4	0.5
Kurtosis		0.8	1.0	0.7	1.1

<u>Surface sediments</u>: Three samples of sediment from the top 30 mm of the stream bed were taken from each station (27/1/73) and analysed as for the whole cores. Results are presented in Table 22 and Figure 8.

At Stations 2 and 4 current velocities were higher (Table 2) and a larger amount of coarse material was present on the surface than in the lower levels (as indicated by a comparison with full cores). This increased coarseness was reflected by the graphic mean values of 2.8 phi and 3.7 phi for Stations 2 and 4 respectively.

FIGURE 8: Mean percent cumulative curves of
(a) top 30 mm and
(b) whole 150 mm cores of sediment taken from four stations in the Leeston drain.

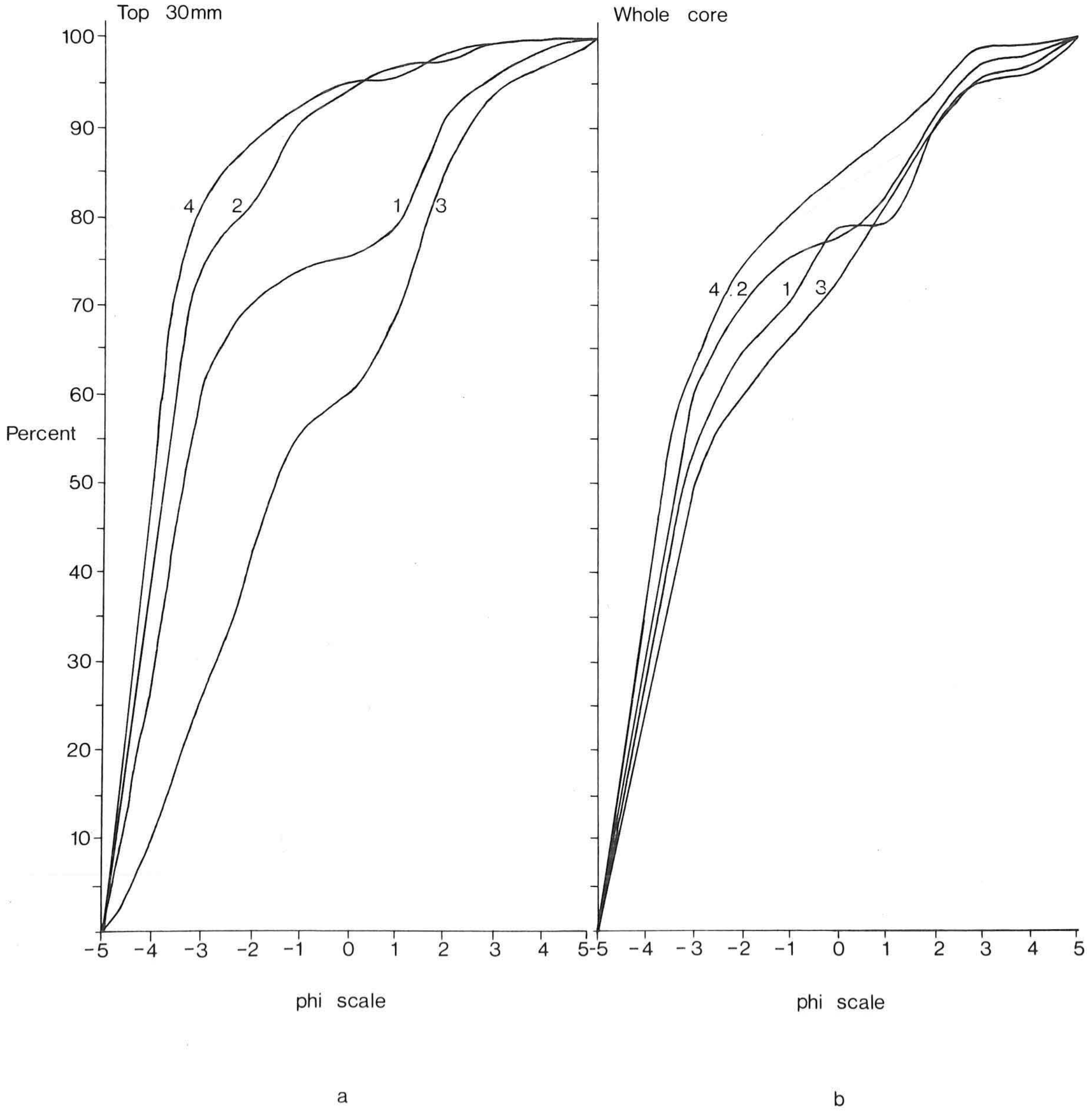

Top 30mm
Whole core
Percent
100
90
80
70
60
50
40
30
20
10
4
2
1
3
-5
-4
-3
-2
-1
0
1
2
3
4
5
phi scale
a
b

TABLE 22: Mean sediment characteristics of the top 30 mm samples from the four stations in the Leeston drain.

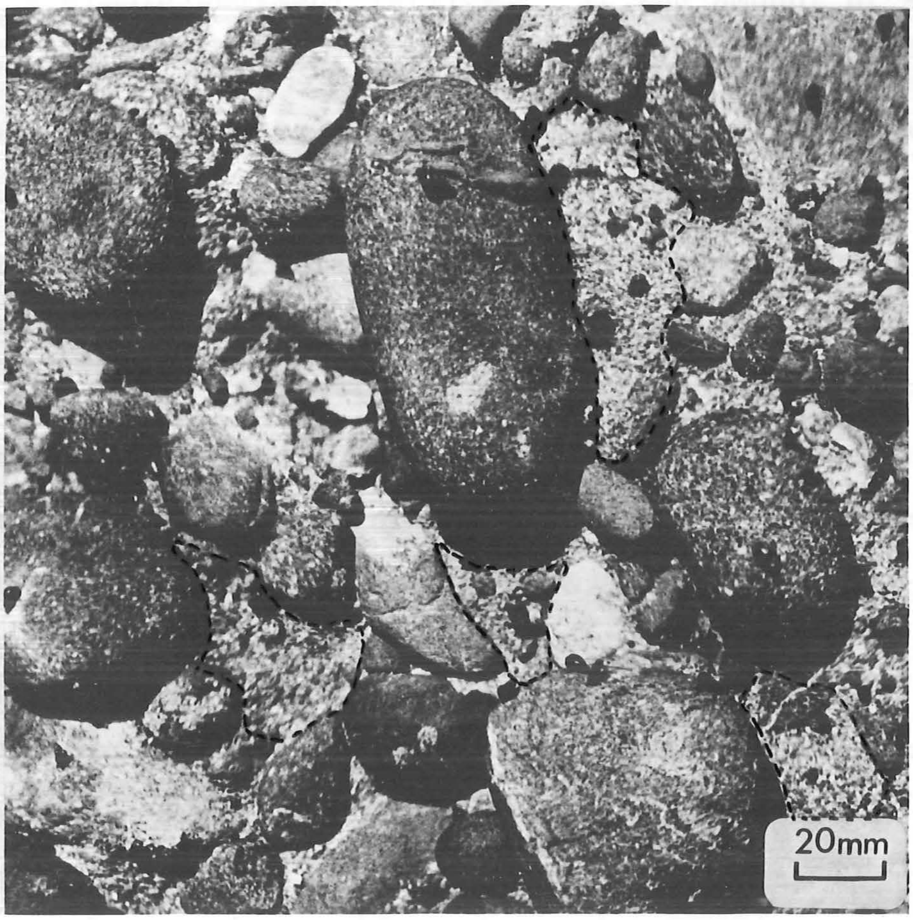
		Stations			
		1	2	3	4
Graphic mean		2.1	2.8	1.8	3.7
Sorting	ø	2.4	1.7	2.5	0.8
Skewness		0.47	0.46	0.45	0.54
kurtosis		0.7	1.3	0.7	1.8

Any finer material present in the surface sediment was probably located in a "dead" zone created by turbulence (Plate 9). Sorting was also greater at these stations and presumably was produced by the "winnowing" effect of the current which removed much of the finer material and thus reduced the range of particle sizes present. As a result of the increase in mean size and sorting, leptokurtic to very leptokurtic values were obtained for the upper layers.

In contrast, with the surface sediments from Stations 2 and 4, those from Stations 1 and 3 were similar to whole core sediments. It appears therefore that the slower water currents at these stations allowed finer materials to accumulate and infiltrate the coarse lattice of the original sediment to a depth of at least 150 mm. This infiltration appeared to be more complete at Station 3 where there was no change in kurtosis between surface and whole cores. However, at Station 1 there was more fine material on the surface as indicated by the more strongly platykurtic value obtained. This additional surface sand appeared to be material discharged by the dairy shed rather than a normal component of the

PLATE 9: A magnified section of the substrate at Station 2 showing location of "dead zones".

(photo: J.W. Marshall).


20mm

sediment. This was suggested by the work of Dyer (1970) who proposed a set of grain size parameters for the analysis of platykurtic sandy-gravel samples which differentiated between contemporaneous and subsequent sand deposition. His method was based on the maximum possible infilling by sand of a simple sediment lattice. If the amount of sand exceeded 25% of the total sediment it was most likely deposited contemporaneously with the remaining sediment. Less than 25% sand was a strong indication that it was deposited at a later date. Calculations showed that Station 1 had between 16 and 25% sand which, according to Dyer (1970) would indicate that the sand had infiltrated at a later date. The increased amount of fine sand in the sediment possibly because of its instability appeared to have an adverse effect on the surface dwelling gastropods, which were present in reduced numbers.

Organic content of sediments: Mean percent organic content of sediments at four stations are expressed in Table 23. Values are given for whole cores, the top 30 mm of the bed and percentage of the fraction less than 63 µm.

TABLE 23: Mean percent organic content by weight in sediment cores from four stations in the Leeston drain.

Station	Whole core*	Upper 30 mm layer	Less than 63 µm fraction
	n = 12	n = 4	n = 6
1	1.8	3.7	3.6
2	1.5	2.1	4.0
3	2.2	3.4	3.7
4	1.7	2.9	4.2

* Organic content of sediments less than 1 mm.

There was a tendency for the organic levels found to reflect the percentage of fine sediment fractions in the samples (Table 20). The percent organic content of the sediment is presented in Table 24.

TABLE 24: The percent organic matter by weight in sediments from four stations in the Leeston drain on 12 sampling days between February 1972 and January 1973.

	Stations			
Date	1	2	3	4
17/2/72	2.1	1.2	2.6	1.3
20/3	1.6	1.2	1.9	1.2
10/4	2.0	2.1	1.9	2.1
Stream cleaned				
1/ 5	1.4	1.4	3.2	2.2
20/ 6	2.1	2.1	2.2	-
24/ 7	2.2	2.1	3.1	2.4
21/ 8	1.7	1.8	2.5	2.1
25/ 9	1.6	1.4	1.5	1.2
24/10	1.4	1.0	2.2	2.1
6/11	2.2	1.7	2.0	1.6
8/12	1.6	1.4	1.9	1.3
8/ 1/73	2.1	1.5	1.9	1.3

The organic content of the top 30 mm was similar at all four stations but there was a marked difference between the top layers and the full core percentages, (Table 23) indicating that the organic matter was mainly confined to the upper layers. At Stations 2 and 4, detritus was on the surface of the sediment, and most appeared to be caught between the larger exposed pebbles. At Station 3 there was little opportunity for detrital accumulation of this kind and the organic fraction was composed largely of small particles which were incorporated into the upper layers of the sediment.

Spatial distribution of sediment sizes: The physical effect of the sediment size on the distribution of the benthic fauna can be pronounced, and the distribution of different sized sediments can alter the distributional patterns of the fauna (Hynes 1970). The presence of large particles on the surface at Stations 2 and 4 conferred considerable physical stability on the sediment and also resulted in water turbulence and "dead" spaces occurring around the larger substrate particles. Large sediment particles also trap detritus and are often capable of supporting epilithic algae and so give rise to a greater range of available food. Where this is the case a diverse fauna is often present (Jaag and Ambühl 1964). Stations 2 and 4 had the most diverse sediment structure of the stations in the Leeston drain and the presence of large exposed particles there probably allowed the development and maintenance of a diverse population. On the other hand fine sediments on the surface, fill the interstices between large particles, remove the dead spaces and decrease turbulence. This results in a reduction in the range of habitats available to the fauna, consequently, there is a reduction in species variation. Such a situation has occurred at Station 3 and to a lesser extent at Station 1. In general, the presence of fine material, with its higher organic content, favours epipelic detritivores e.g. Potamopyrgus antipodarum and Physa sp., filter feeders such as Sphaerium novaezelandiae and fine particle feeding oligochaetes. However, if the fine sediment is unstable as at Station 1 numbers of epibenthic grazers like P. antipodarum and Physa sp. are reduced. The findings of Nuttall (1972) substantiate this observation.

Accumulation and enhancement of fine sediments: Associated with the reduction in sediment size found at Station 3 it is probable that there was an increase in the microbial activity of the sediments. This increased activity may have been partly the normal result of a decrease in sediment size, and may also be because of an increased concentration of microbial populations carried by eutrophic water (Table 5). Fine sediment particles become carriers of, and usually contain, a much higher percentage of organic material than the larger fractions as shown in Table 23. Fine sediments at the mud-water interface have an increased ionic activity (Malcolm and Kennedy 1970) and collect fine suspended organic particles and dissolved organic material from the water as it passes. This suspended organic material can also flocculate while in suspension and precipitate out as larger aggregates. The mechanism for this process is complex and poorly understood but it has been shown that the presence of high nutrient concentrations associated with high pH levels will initiate a precipitation reaction. Such conditions are often found in sewerage treatment waters. Hemens and Mason (1968) working with sewerage water demonstrated that as the pH increased in an experimental stream, phosphate precipitated out of solution as granules combined with algal cells. With the presence of high pH and nutrient at Station 3 such a mechanism could account in part for the presence of increased fine sediment which is found in large amounts at this station as no obvious major source of this fine material could be found (cf. Station 1).

Another means of sediment accumulation is by plant and bacterial action within the stream. The root hairs of aquatic plants have been observed to accumulate suspended material (Scoffin 1970) and the growth habits of *Nasturtium microphyllum* at Station 3 appear to act as a filter by trapping particulate material, and by slowing down the current so allowing the heavier sediment particles to fall out of suspension. Algal mats have a similar sediment trapping ability and the artificial substrate experiments carried out by the author in the Leeston drain demonstrated the sediment trapping capabilities of such growths. *Sphaerotilus*, which is found at Station 3, also accumulated large amounts of sediment on its surface.

Biotic interactions with sediments: Fine sediment particles ingested by members of the benthic fauna are frequently unassimilated and evidence obtained by Coler *et al*. (1967), and Newell (1965) suggests that the fine fraction acts as a carrier of high energy microbial colonies which are utilised as food. Surface grazing gastropods such as *Potamopyrgus antipodarum* ingest large amounts of this fine material and the resulting faeces may be sites for renewed microbial activity (Hargrave 1970).

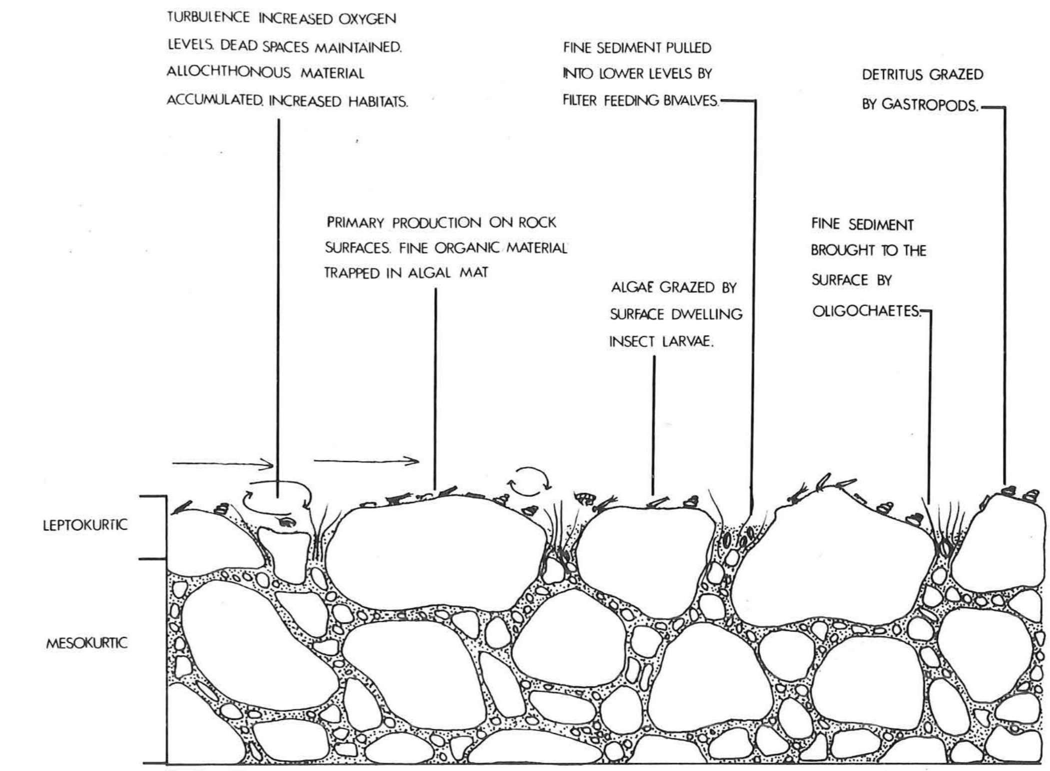
The fresh water clam, *Corbicula flumina*, studied by Prokopovich (1969) filters particles out of suspension and binds them together with an organic binder to produce pseudofaeces which are deposited on the surface. In this manner fine sediment can be laid down against a hydraulic gradient. The well consolidated faeces of P. antipodarum and Physa sp. could also act in this manner and in view of the high density of gastropods found at Station 3 (up to 49 300 per m^2) the effect on fine sediment accumulation by this method could be significant.

The filtering processes of Pisidium sp. was studied by Jonasson (1972) and Meier - Brook (1969) who found that fine surface sediment was pulled into the lower layers where it was again deposited as psuedo - faeces. Sphaerium novaezelandiae a member of the same family as Pisidium was found in the finer sediments of the Leeston drain and it is likely that its mode of feeding was similar to that described above. The activity of this species may contribute to the even spread of fine organic material throughout the sediments especially at Station 3 where they are most common. At the same time as the sediment is being consolidated on and below the surface, the activities of oligochaetes bring large amounts of fine sediment to the surface as faeces (Appleby and Brinkhurst 1970; Jonasson 1972). Some of this material can then be recolonised by microbes and some will be washed away by the current. Worm activity is probably of considerable importance in distributing sediments especially at Station 3 where a mean density of 76 490 oligochaetes per m^2 was found.

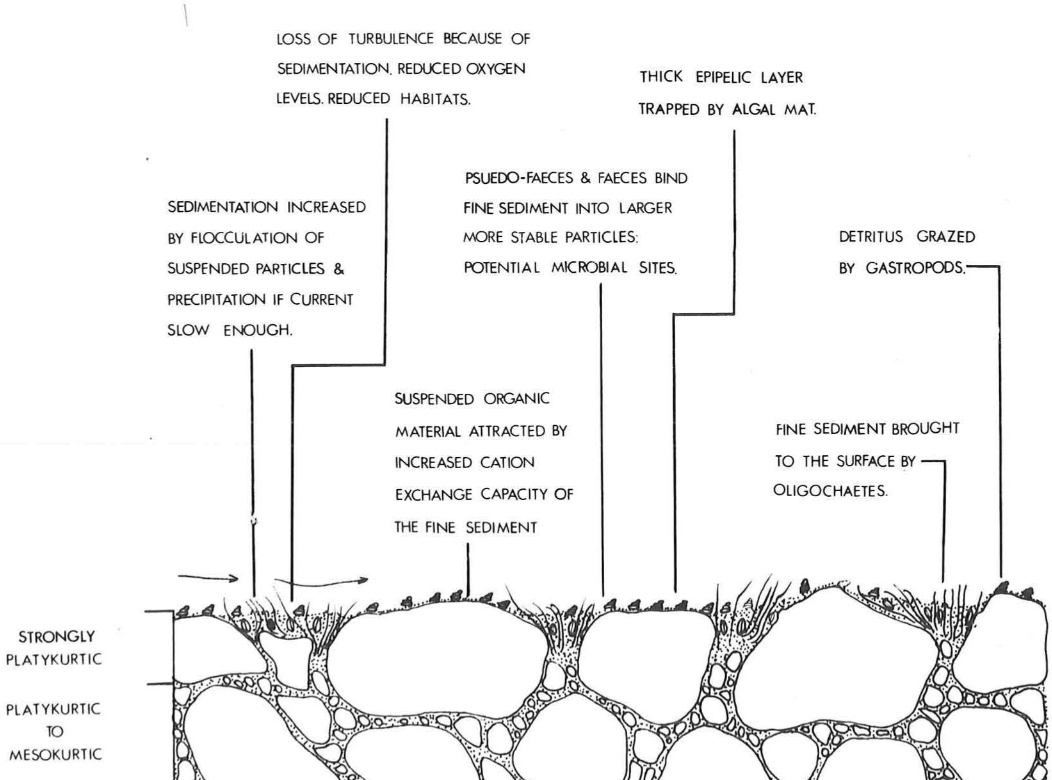
5.5 Conclusion

At all stations in the Leeston drain the substrate has a common origin and similar composition, and any variations which occur are produced by different environmental conditions prevailing at each station. Fast water currents remove fine fractions whereas slow currents allow a build up of fine sediment. Two stations in the Leeston drain have been extensively modified, one by the addition of fine sand, and the other by the accumulation of fine organic mud. The organic content of the sediment is concentrated in the surface layers and is highest in fine sediments. Deposition and accumulation of fine sediments are dependent on current velocity but is also strongly influenced by biotic activity. A synthesis of these factors and their effects on a clean and a polluted section of a shingle stream are presented in Figure 9.

FIGURE 9: Diagramatic representation of some factors influencing the substrate and fauna in oligotrophic and eutrophic sections of a shingle stream.



OLIGOTROPHIC CONDITIONS.



EUTROPHIC CONDITIONS.

6 BENTHIC FAUNA

6.1 Introduction

The results of benthic sampling are presented in three stages and the first stage presents the biology of individual species selected because of their abundance, rarity or interest. The second is a presentation of combined faunal groups both as total numbers and total standing crops. Finally, species diversity calculated to provide objective comparisons between stations is discussed in Chapter Seven.

As a result of this study an illustrated key of to the local fresh water oligochaetes was constructed and is presented in Appendix 1.

6.2 Biology of Individual Species

Lumbriculidae:

Stylodrilus heringianus Claparède (Figure 10)

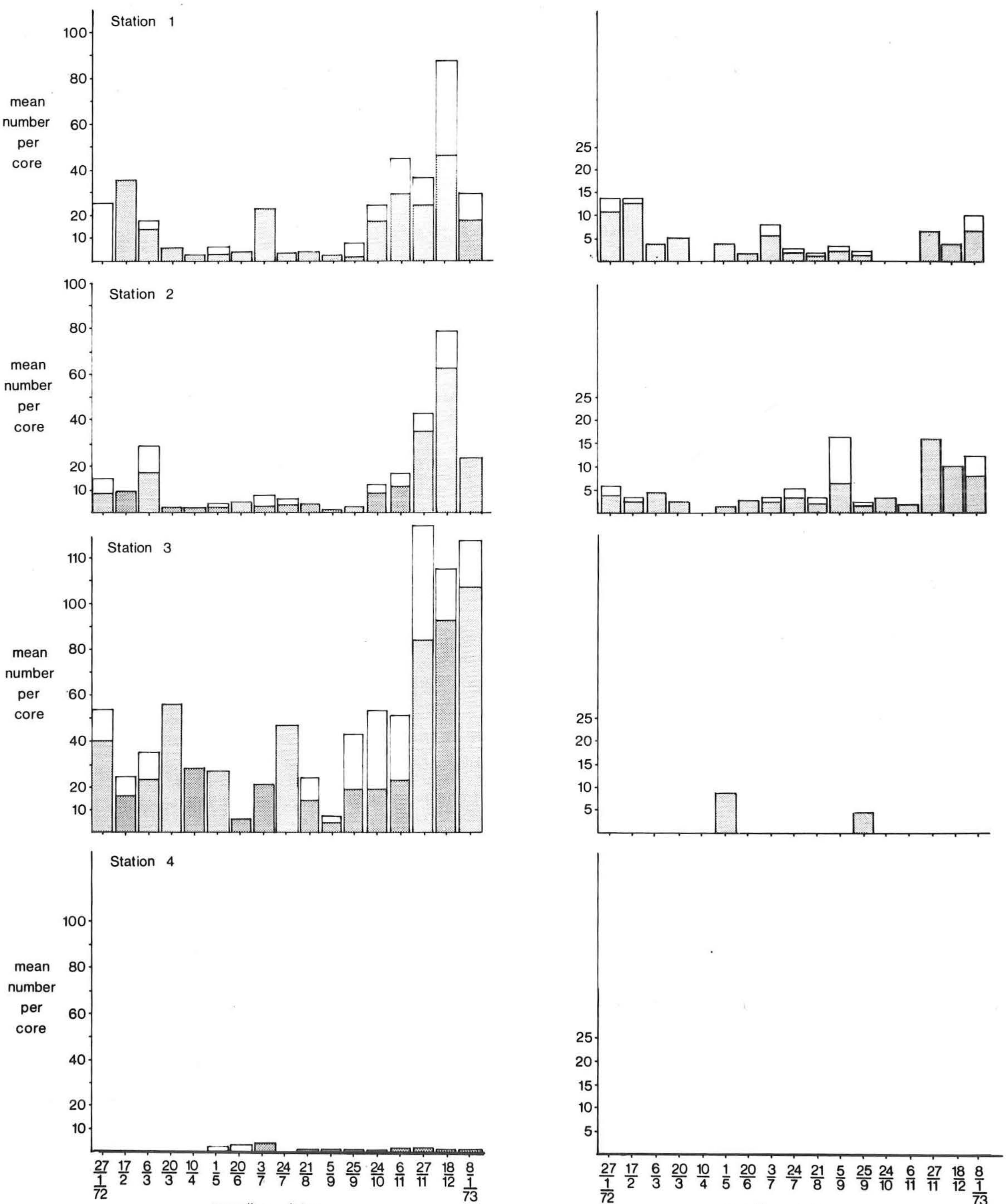
The genus *Stylodrilus* (Lumbriculidae) is recorded in the Southern Hemisphere for the first time. *Stylodrilus heringianus* superficially resembles *Lumbriculus variegatus* in size and shape but is readily distinguished from it by different shaped chaetae and by the occurrence of a sexually mature stage which is marked by the development of a pair of everted penes on segment 10 (Brinkhurst 1963). Numbers of this species increased in late spring and continued to increase until late summer, when maximum numbers (13/sample) were reached. After this, numbers declined and were low throughout autumn and winter. Initiation of the mature period began about early spring and reached a peak in mid spring when more than 50% of the worms collected had well developed clitella and genitalia. This species is more habitat specific than most freshwater oligochaetes, Brinkhurst (1963) having described the habitat as the sands and gravels of stony streams. The presence of S. heringianus at Stations 1 and 2 is in accord with Brinkhurst's observations as the substrate at these stations consists of a mixture of coarse sand and gravel. It was not common at Station 3 which may indicate that either the sediment was too fine or the conditions were too eutrophic for it to occur. Its absence from Station 4 can probably be accounted for by the lack of fine sands and clay between the larger gravels.

Lumbriculus variegatus (Müller) (Figure 10)

This cosmopolitan lumbriculid is widespread in New Zealand's running waters and is thought to have been introduced into the country (Brinkhurst 1971). If this was the case it has spread very widely since its introduction. Numbers of L. variegatus taken from each station varied but there was an overall increase in spring and summer. The maximum mean number recorded was 135 per sample. Sexually mature individuals of this species are rarely observed although they have been found in Newfoundland by Pickavance (1971) and in Britain by Cook (1967, 1969). No sexually mature specimens were found during this study. Reproduction is predominantly asexual, worms breaking into two viable "bits" which regenerate anterior or posterior segments.

At Stations 1 and 2, L. variegatus began to multiply about the beginning of spring and regenerating worms occurred in the samples until early autumn. This is in contrast to

FIGURE 10: Mean numbers of _Lumbriculus variegatus_ (left) and of _Stylodrilus heringianus_ (right) found at four stations in the Leeston drain between 27/1/72 and 8/1/73.



Station 1
Station 2
Station 3
Station 4
mean number per core
100
80
60
40
20
10
110
25
15
5
27/1/72 17/2 6/3 20/3 10/4 1/5 20/6 3/7 24/7 21/8 5/9 25/9 24/10 6/11 27/11 18/12 8/1/73
sampling dates

the findings of Cook (1969) who found that fragmentation occurred at all seasons in England. Reproduction began at Station 3 a month earlier than at the other stations but all reproduction had stopped by early autumn. The autumn decline in numbers of L. variegatus at Station 2 was not as marked ~~as~~ at Station 3 which tends to suggest that the fine sediment with its high organic content was capable not only of supporting a larger number of worms but also of maintaining them throughout the year. A similar trend was found at Station 1 as at Station 3 but it was not as pronounced.

The regeneration cycle therefore appears to be one of spring and summer divisions followed by regeneration throughout autumn and winter, the resulting mature worms reproducing the following spring. The presence of low numbers of worms in winter suggests that mortality of regenerating worms is high. This may especially be so for anterior regenerating "bits" which Pickavance (1971) observed were always fewer in number than posterior regenerating "bits".

Clearly, L. variegatus does not have as limited a habitat tolerance as S. heringianus but it was apparent, that finer sediments and higher organic levels maintained larger numbers than coarser less enriched sediments.

Tubificidae:

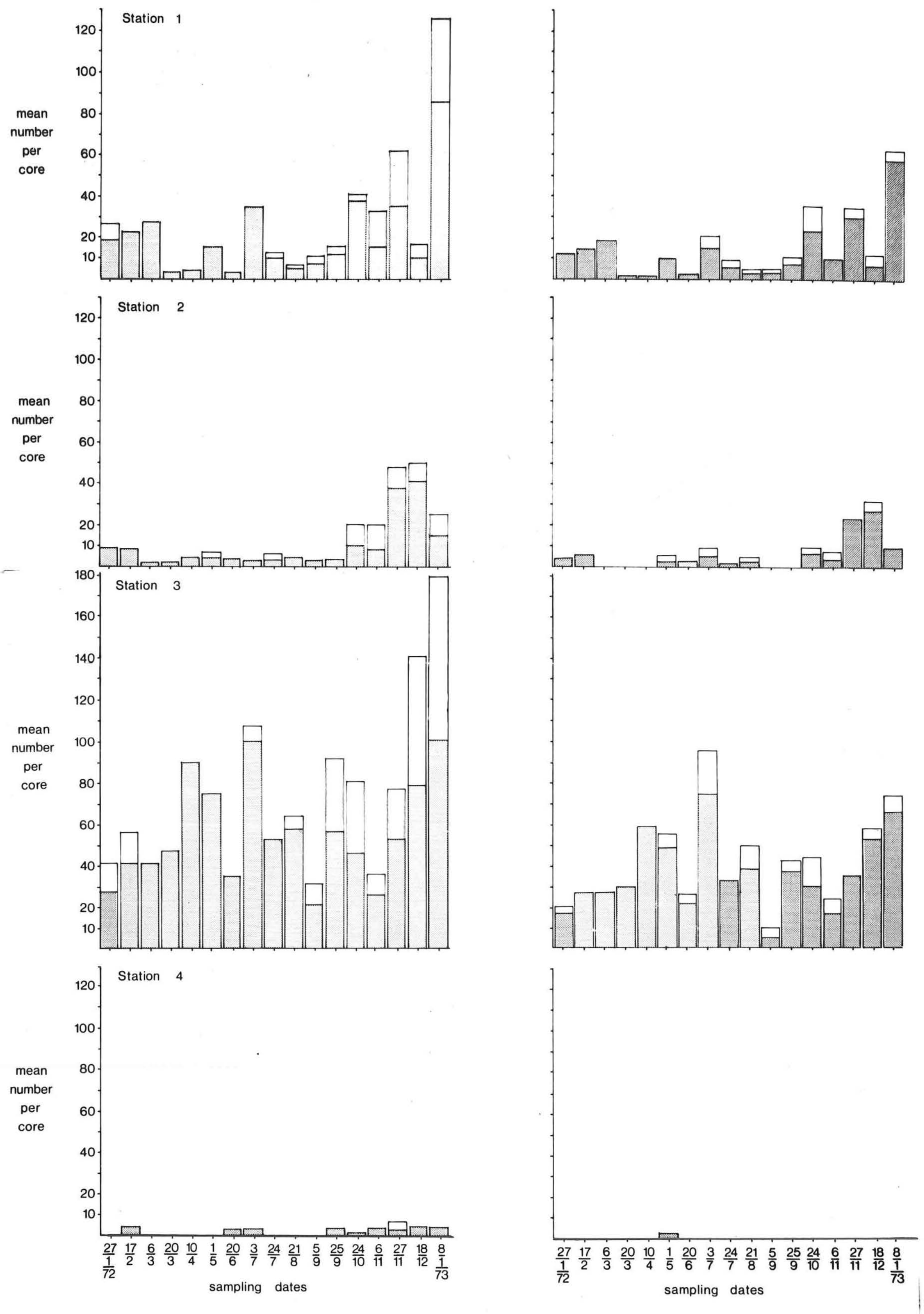
Tubifex tubifex (Müller) (Figure 11)

The name Tubifex tubifex is traditionally associated with small oligochaetes found in freshwater, but it is doubtful if this species is as numerically significant in polluted waters as it is often quoted to be. The present study has shown that a number of oligochaete species are likely to be found in both clean and "polluted" stream situations, rather than one or two species as many people have assumed. This assumption most probably arose as a result of difficulties in the identification of tubificid species especially when immature.

In this study immature T. tubifex could not be distinguished from immature Potamothrix bavaricus. To calculate the number of immature worms of each species the ratio of mature T. tubifex to mature P. bavaricus was calculated for each sample period and applied to the total number of immature tubificids present in that sample. When mature the gentilia provide conclusive characters for identification and have now been described in most species (Brinkhurst and Jamieson 1971). Tubifex tubifex does occur in large numbers at polluted stations such as Stations 1 and 3 and is also common at cleaner stations. Tubifex tubifex exhibited marked seasonal fluctuations in mean numbers (0-50/sample) at the clean stations and at the polluted stations the mean numbers were always greater (33-179/sample).

Tubifex tubifex had a sexually mature period which started about July and reached a peak in late spring - early summer, when up to 50% of the total number of worms present were sexually mature. When the worm begins to mature there is a thickening of the genital segments and a cream-white granular belt develops around the 13th and 14th segments. As the animal matures these cells become denser and the distinctive chitinous penis sheath, pear-shaped atrium and vas deferens which coils around the body cavity are readily observed at 400 x magnification (Plate 10). At the end of

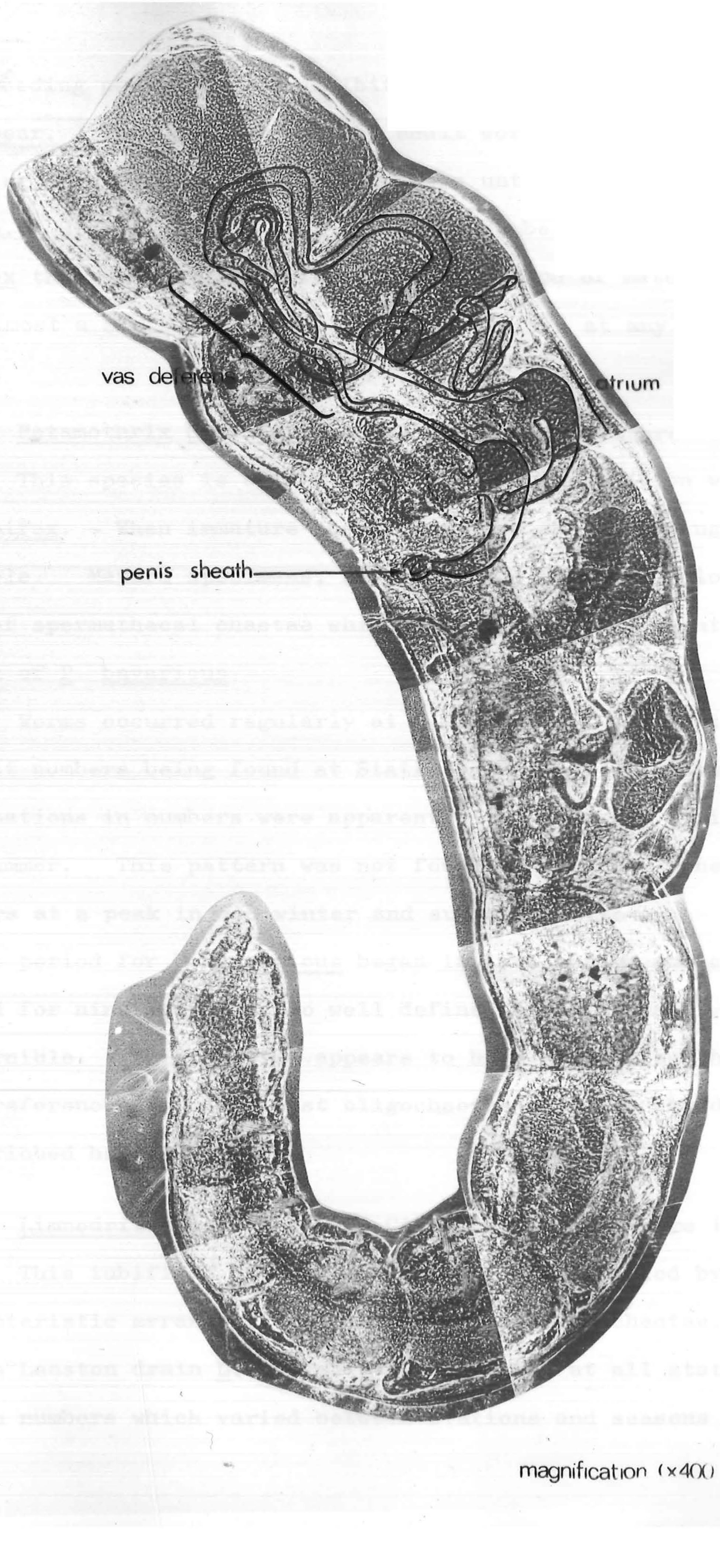
FIGURE 11: Mean numbers of _Tubifex tubifex_ (left) and of _Potamothrix bavaricus_ (right) found at four stations in the Leeston drain between 27/1/72 and 8/1/73.



Station 1
Station 2
Station 3
Station 4
mean number per core
sampling dates

PLATE 10: Anterior segments of a mature *Tubifex tubifex* showing well developed genitalia.

(photo: J.W. Marshall).


vas deferens
atrium
penis sheath
magnification (×400)

the breeding period, worms exhibiting mature characteristics disappear. This could mean that adult worms die after breeding, or that the genitalia regress until the following season. Station 3 supported a greater number of mature T. tubifex than any other station, and the period of maturity was almost a month longer at this station than at any other.

Potamothrix bavaricus (Öschmann) (Figure 11)

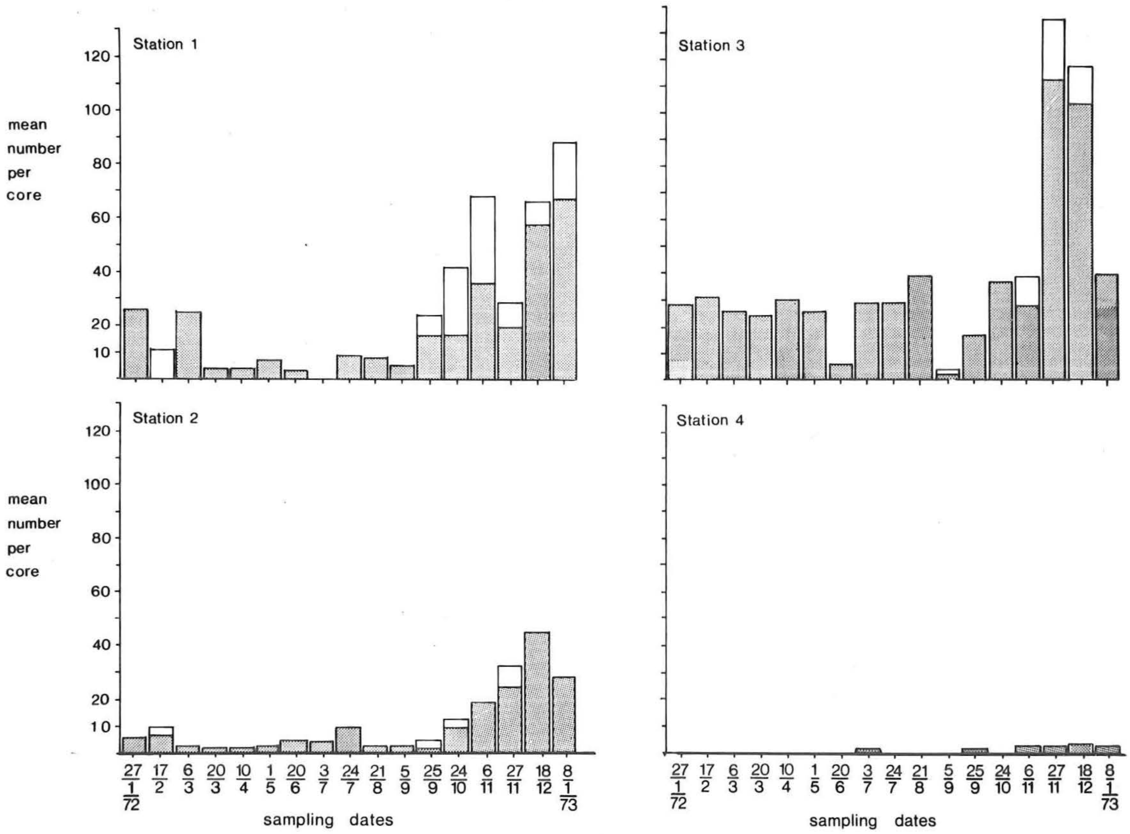
This species is common and occurs in conjunction with T. tubifex. When immature the two species are indistinguishable. Mature specimens, however, have a well developed pair of spermathecal chaetae which provide positive identification of P. bavaricus.

Worms occurred regularly at Stations 1, 2 and 3 with highest numbers being found at Stations 1 and 3. Seasonal fluctuations in numbers were apparent with maxima in spring and summer. This pattern was not found at Station 3 where numbers at a peak in mid winter and summer. The mature period for P. bavaricus began in late autumn and continued for nine months. No well defined breeding peak was discernible. This species appears to have generalised habitat preferences but like most oligochaetes was more abundant in enriched habitats.

Limnodrilus hoffmeisteri Claparède (Figure 12)

This tubificid is common and readily identified by the characteristic arrangement of its hairless bifid chaetae. In the Leeston drain L. hoffmeisteri occurred at all stations and in numbers which varied between stations and seasons in

FIGURE 12: Mean numbers of *Limnodrilus hoffmeisteri* found at four stations in the Leeston drain between 27/1/72 and 8/1/73.



Station 1
Station 2
Station 3
Station 4
mean
number
per
core
120
100
80
60
40
20
10
27/1/72
17/2
6/3
20/3
10/4
1/5
20/6
3/7
24/7
21/8
5/9
25/9
24/10
6/11
27/11
18/12
8/1/73
sampling dates

a manner similar to other tubificids. The period of sexual maturity was well defined, starting in late September and ending abruptly in early January. A shorter period of maturity (November to December) was found at Station 3 than at other stations. Another member of this genus, *Limnodrilus udekemianus* Claparède, was also found, but only in small numbers.

Mature specimens of the two species of *Limnodrilus* could be separated readily on the basis of penis sheath length, *L. udekemianus* having a much shorter sheath. Immature worms of these two species could also be separated as they have different shaped chaetae.

Telmatodrilus multiprostatus Brinkhurst (Figure 13)

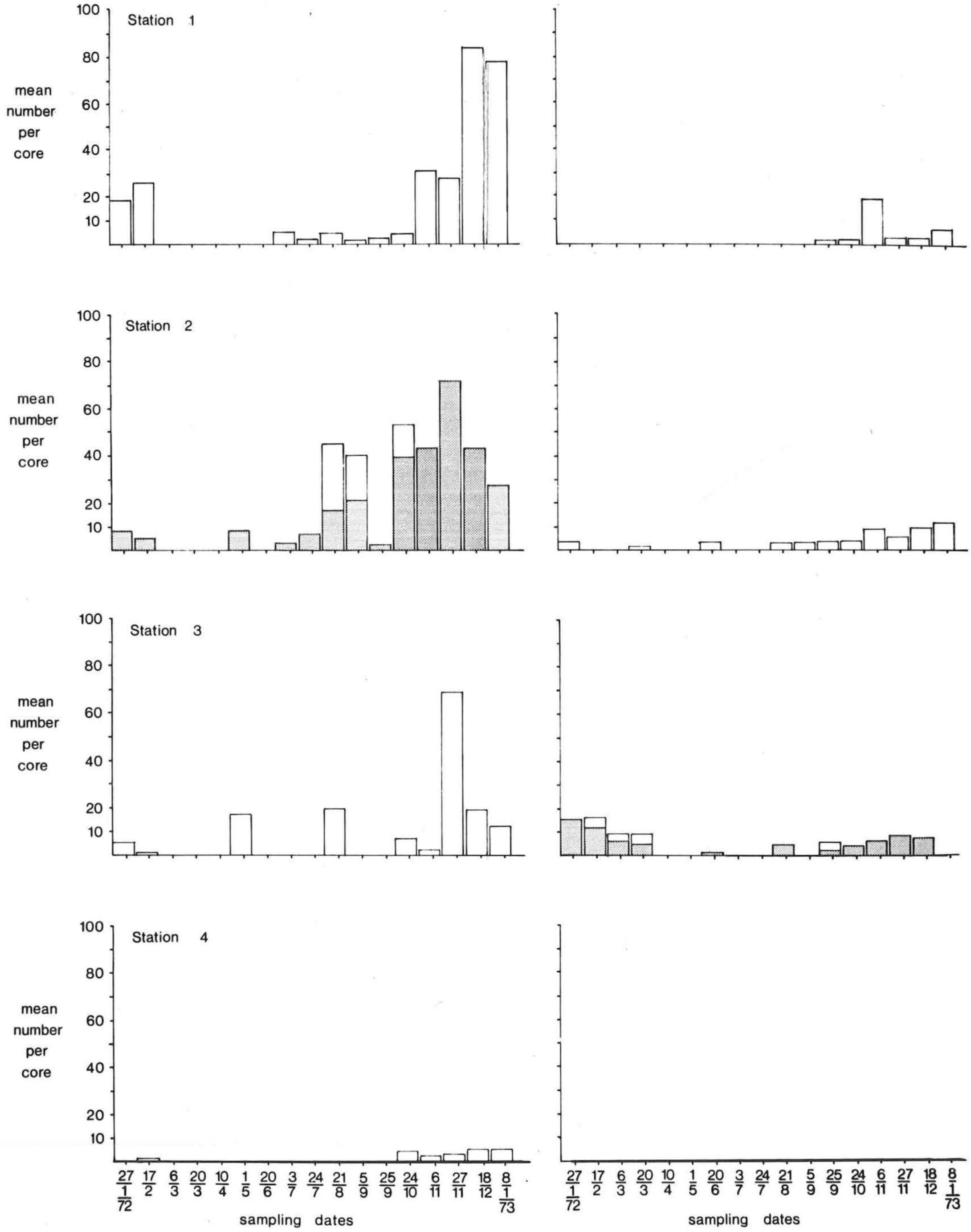
Telmatodrilus multiprostatus occurred in low numbers (1-20/sample) throughout most of the year, although slight seasonal increases in numbers during spring and summer were observed. This species did not show any marked habitat preferences but mature specimens were found only at Station 3. The period of maturation was late summer to mid autumn, a time, when most other species of oligochaete had finished breeding. A single mature individual was also found in early spring.

Naididae:

Nais elinguis Müller (Figure 13)

Individuals of this small (length, 2.2 - 21 mm) transparent species were collected at all stations throughout the year. Numbers fluctuated (0-85/sample) but reached a peak in late spring - early summer. Highest densities per sample were found at Station 1 whereas the enriched Station 3 had low

FIGURE 13: Mean numbers of <u>Nais elinguis</u> (left) and of <u>Telmatodrilus multiprostatus</u> (right) found at four stations in the Leeston drain between 27/1/72 and 8/1/73.



Station 1
Station 2
Station 3
Station 4
mean number per core
100
80
60
40
20
10
27/1/72 17/2 6/3 20/3 10/4 1/5 20/6 3/7 24/7 21/8 5/9 25/9 24/10 6/11 27/11 18/12 8/1/73
sampling dates

numbers throughout most of the year. This appears to conflict with the findings of Wachs (1967) who noted that this species was abundant in enriched situations. Very low numbers occurred at Station 4. The maturity period was brief and occurred in late winter - early spring, when more than 50% of the worms collected were mature. A related species, Nais variabilis Piguet, was occasionally collected with N. elinguis but never in numbers greater than 10 per sample. Differentiation between the two species was based on chaetal differences, N. elinguis having fine, long parallel teeth whereas N. variabilis has short diverging teeth.

Oligochaete cocoons

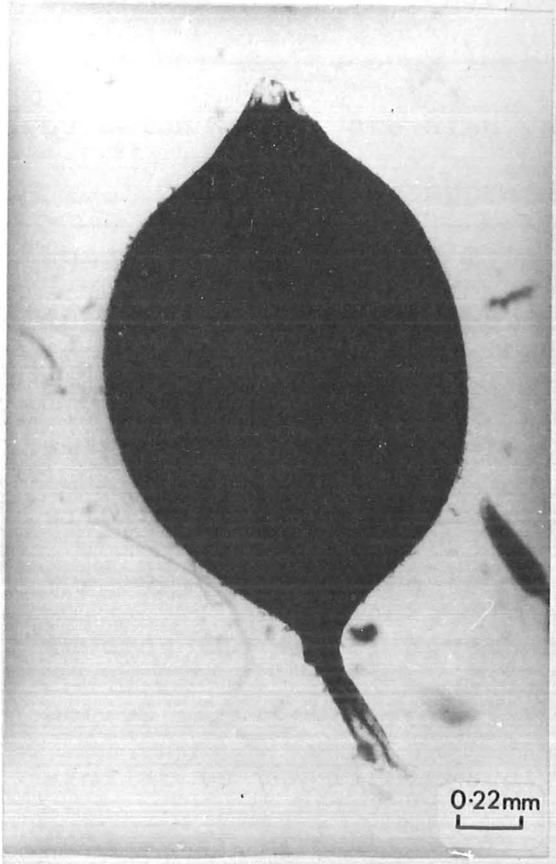
Cocoons are laid in stream bed sediment and are clear to creamy white. Three types of cocoon could be differentiated in this study. One type was positively identified as belonging to the Lumbricid, Eiseniella tetraedra (Savigny), and could be distinguished from the others by its larger size (1.75 mm long by 1.25 mm diameter) (Plate 11). It is oval with a cap (0.75 mm in diameter) at one end and a elongated "tail" (0.25 mm long) at the other. As the embryos develop the cocoon changes colour from creamy white to tan.

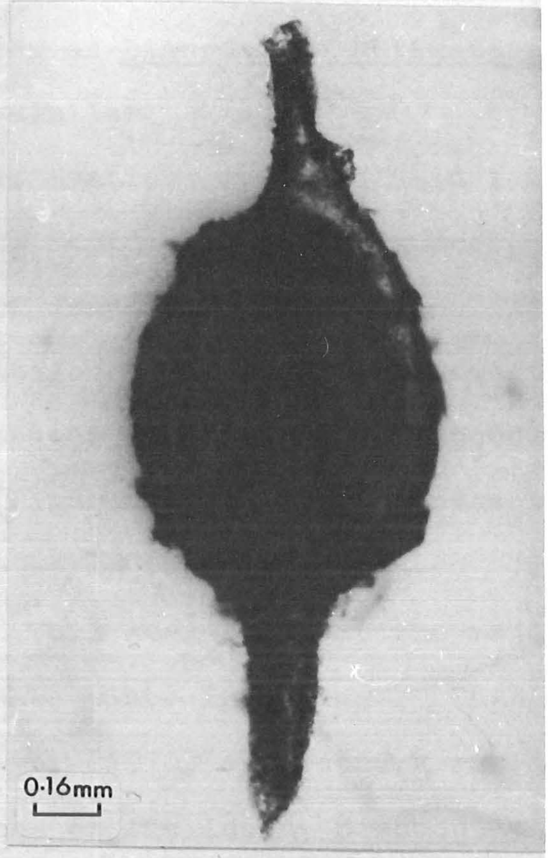
The species to which the other two types of cocoon belonged were not determined. Type two (Plate 11) was spherical (0.7 mm diameter) and white, with two projecting spines which add 0.5 mm to the cocoons total length. The third type was the most common and was oval with a mean length of 1.5 mm and a diameter of 0.7 mm (Plate 11). At each end of these clear cocoons was a hollow constricted tube 0.1 mm in diameter and 0.2 mm long. Cocoons produced by T. tubifex

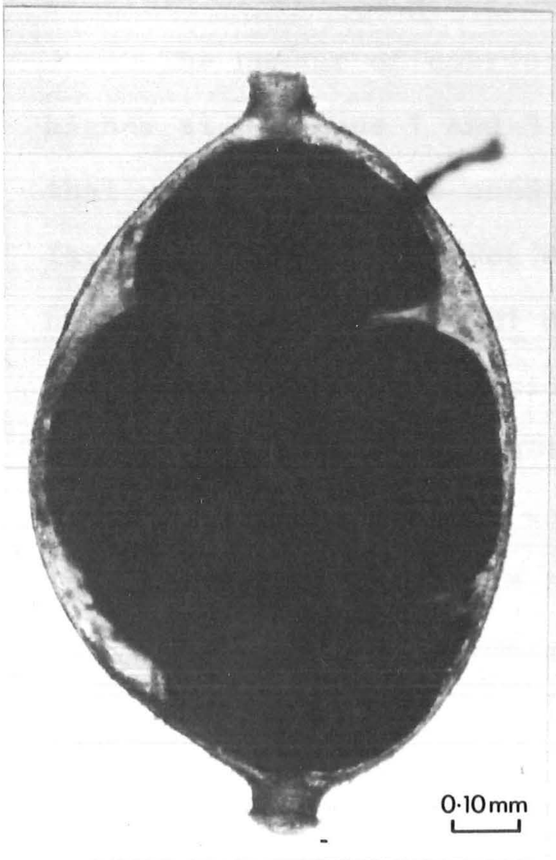
PLATE 11:

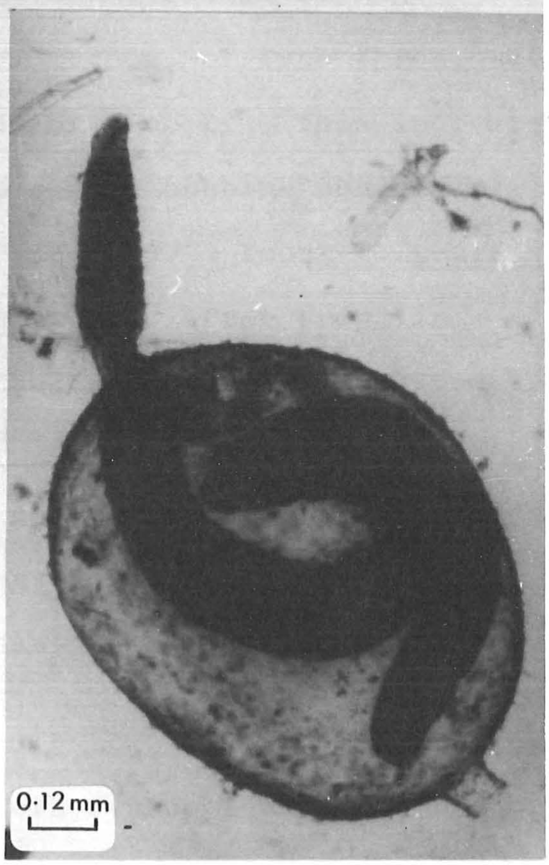
a.	*Eiseniella tetraedra* cocoon	(top left)
b.	Type two cocoon	(top right)
c.	Type three cocoon	(bottom left)
d.	*Tubifex tubifex* embryo emerging through the constructed end of the cocoon	(bottom right)

(photos: F. McGregor).


0·22mm


0·16mm


0·10mm


0·12mm

under experimental conditions were very similar to type three but the cocoons identified as Limnodrilus hoffmeisteri by Aston (1973) are also very similar.

Cocoons first appeared at Stations 1, 3 and 4 in late August and at Station 2 in late September, and were present in all samples until the end of January (Figure 14). Highest numbers occurred at Station 3 and they were lowest at Stations 2 and 4. The presence of cocoons corresponded with the periods of maturity (Figure 14) of most species but the ratio of cocoons to mature worms rapidly decreased towards the end of November. This suggests that the major period of cocoon production takes place in spring. This is similar to the findings of Sawyer (1970) who found a rapid fall - off in numbers of cocoons of the leech, Erpobdella punctata (Leidy), after an initial burst of laying.

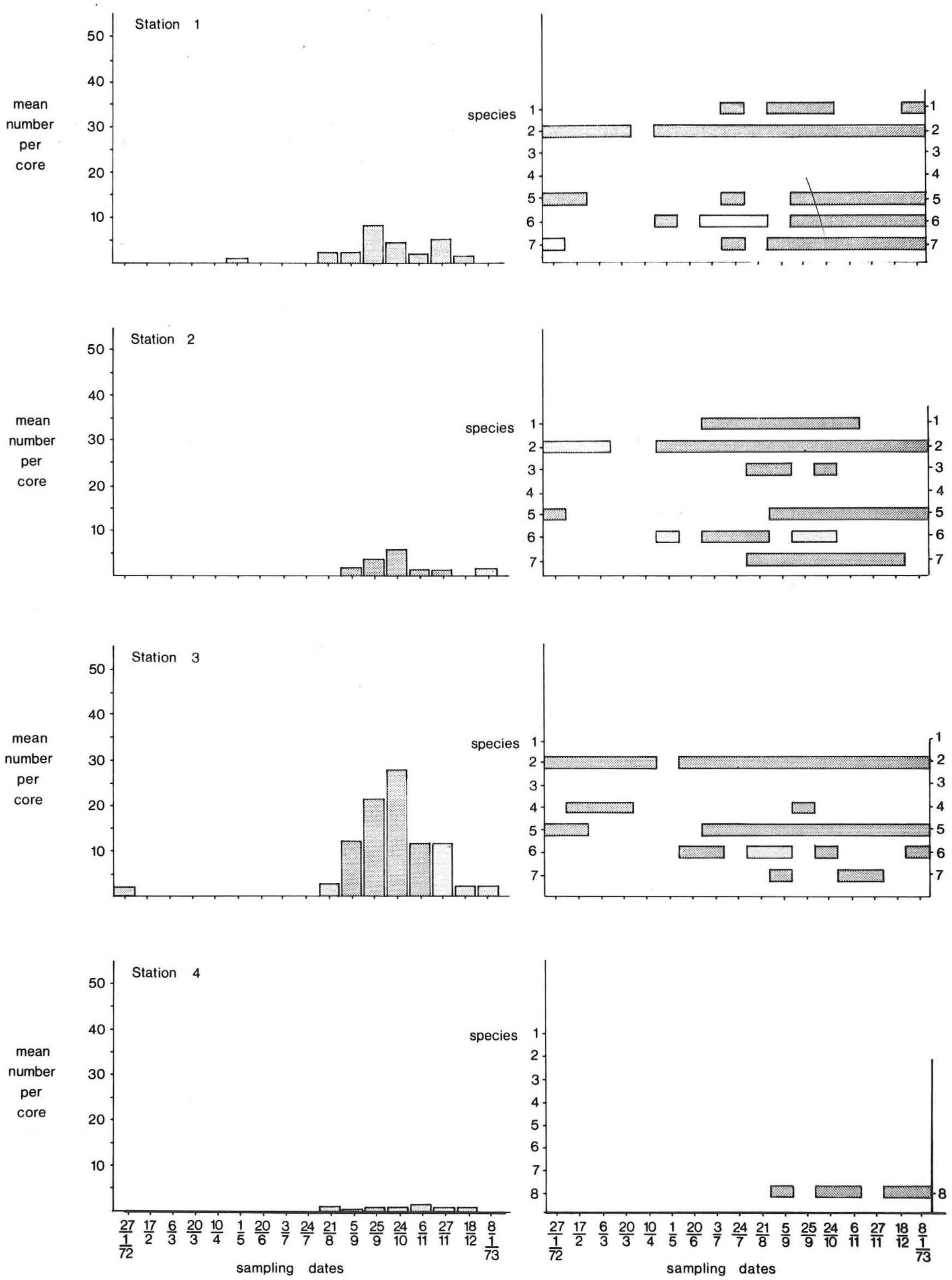
The number of embryos per cocoon, of type three, was higher at Stations 1 and 3 than Station 2. This indicates that under favourable conditions more cocoons containing larger numbers of embryos are produced. Young T. tubifex hatch in approximately 21 days at 20°C after wriggling vigorously around the inside the cocoon until they find the hollow tube through which they leave (Plate 11). There is no rupture of the cocoon wall as is the case in E. tetraedra. The emergence process was observed to take up to five minutes, the young worms which emerge having yolk yoke cells in the gut.

Nematoda: (Figure 15)

Members of this phylum were found at all stations but no attempt was made to distinguish species. Highest numbers were found at Station 3 (a maximum of 90/sample) and there was

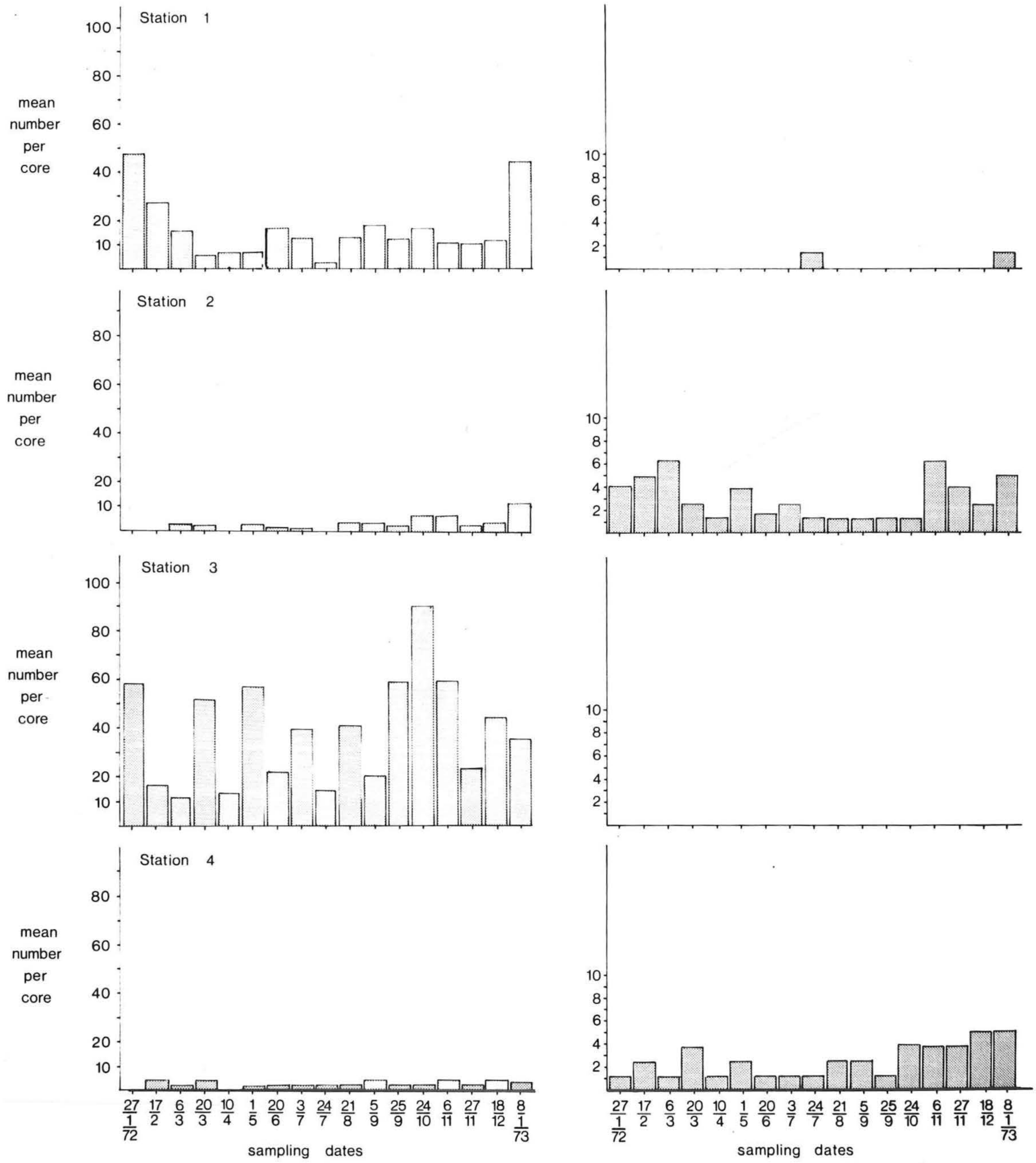
FIGURE 14: Mean number of cocoons found at four stations between 27/1/72 and 8/1/73 (left). Periods of maturity for the major oligochaete species found in the Leeston drain (right).

Key: 1 = Stylodrilus heringianus
2 = Lumbriculus variegatus
3 = Nais elinguis
4 = Telmatodrilus multiprostatus
5 = Tubifex tubifex
6 = Potamothrix bavaricus
7 = Limnodrilus hoffmeisteri
8 = Eiseniella tetraedra



Station 1
Station 2
Station 3
Station 4
mean number per core
50
40
30
20
10
species
1
2
3
4
5
6
7
8
27/1/72
17/2
6/3
20/3
10/4
1/5
20/6
3/7
24/7
21/8
5/9
25/9
24/10
6/11
27/11
18/12
8/1/73
sampling dates

FIGURE 15: Mean numbers of Nematoda (left) and of El~~i~~midae (right) found at four stations in the Leeston drain between 27/1/72 and 8/1/73.


Station 1
Station 2
Station 3
Station 4
mean number per core
100
80
60
40
20
10
2
4
6
8
10
27/1/72
17/2
6/3
20/3
10/4
1/5
20/6
3/7
24/7
21/8
5/9
25/9
24/10
6/11
27/11
18/12
8/1/73
sampling dates

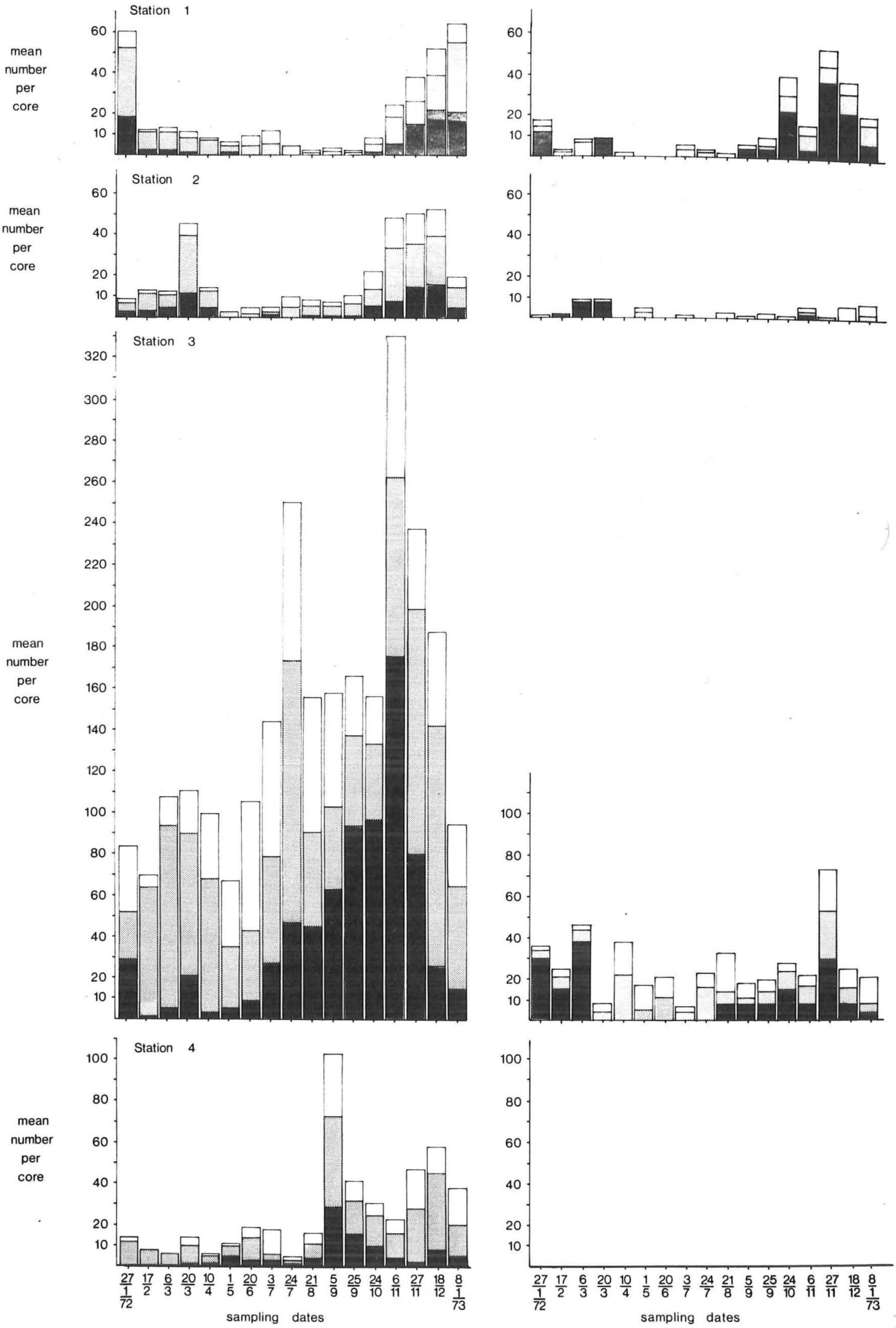
a decline in numbers from Stations 1, 2 to 4 respectively. Largest numbers were therefore found at stations that received some form of pollution and had finer more enriched sediments. Baliga et al. (1969) also found significant increases in nematodes below sewerage outfalls in Illinois, U.S.A. Jansson (1967) and Wieser (1960) have commented that the interstitial pore size of the sediment has a great influence on the movement of nematodes. The presence of fine material at Stations 1 and 3 could therefore account, at least in part, for the higher numbers of nematodes found. There was no marked seasonal fluctuation in numbers of this group at any station.

Mollusca:

Potamopyrgus antipodarum (Gray) (Figure 16)

This ubiquitous gastropod was abundant throughout the Leeston drain. Greatest densities occurred at Station 3 and in late spring - early summer mean numbers reached up to 333 per sample. At Station 3 lowest mean numbers occurred in autumn (111/sample) whereas at Stations 1 and 2 very low numbers (10-20/sample) were found in late autumn - early winter, and peak numbers were not reached until early summer. At Station 4 a slightly different situation was found, an increase in numbers occurring in early spring followed by a decline to low levels in summer. The build-up in numbers during spring and summer was caused primarily by increased production and release of young snails. Numbers of medium (shell length greater than 1.5 mm and less than 3.5 mm) and large (greater than 3.5 mm) P. antipodarum were relatively stable throughout the year. Some small (less than 1.5 mm) P. antipodarum were present throughout the year but their maximum occurrence varied

FIGURE 16: Mean numbers of Potamopyrgus antipodarum (left) and of Sphaerium novaezelandiae (right) found at four stations in the Leeston drain between 27/1/72 and 8/1/73.


Station 1
Station 2
Station 3
Station 4
mean number per core
60
40
20
10
320
300
280
260
240
220
200
180
160
140
120
100
80
27/1/72 17/2 6/3 20/3 10/4 1/5 20/6 3/7 24/7 21/8 5/9 25/9 24/10 6/11 27/11 18/12 8/1/73
sampling dates

between stations. A similar situation was also observed by Winterbourn (1970) in two ponds and a stream in the Manawatu. At Station 3, numbers of small P. antipodarum increased in July and reached a peak in November. On the other hand, Station 4 had high numbers in September after which they declined rapidly. Samples from Stations 1 and 2 did not contain small P. antipodarum until October, but they were present throughout summer and did not decline until towards the end of January. The habitat preference of this species is broad and it was found in fast, clear-flowing water as well as slowly flowing enriched water. The only obvious preference shown in this study was for a reasonably stable substrate. The presence of shifting surface sand at Station 1 probably accounted for the lower numbers of P. antipodarum occurring there.

Sphaerium novaezelandiae Deshayes (Figure 16)

Greatest numbers of this species occurred at Stations 1 and 3 where fine sediments were most abundant. Much lower numbers occurred in the coarser substrate of Station 2. Station 4 with its hard clay base, did not support this species. Large (shell length greater than 5 mm) animals became mature about the end of winter, and about August released small (less than 1 mm) young from the brood pouch in the gills. These young developed through the summer and autumn when there was an increase in the medium size (greater than 2 - less than 5 mm) class. Production of young declined towards the end of March and as a result samples at this time were made up of medium or large animals. Station 1 showed a decline in numbers during late autumn and winter but no pronounced decline was found at Station 3. Sphaerium novaezelandiae has been found in substrates containing fine sediment by Fowles (1972) and was found at Stations 1, 2 and 3 of the Leeston drain.

Crustacea:

Austridotea annectens Nicholls (Figure 17)

This poorly known isopod occurred only at Station 2 where it was quite common, small numbers (mean number 3/sample) being collected in most months. During late spring - early autumn small (less than 20 mm long) isopods were found along with large (greater than 80 mm long) animals, but by late summer, medium sized (20-80 mm long) isopods were found exclusively. This suggests that adults die off at the end of the breeding period and that the medium sized animals present were the small animals of the previous spring and summer.

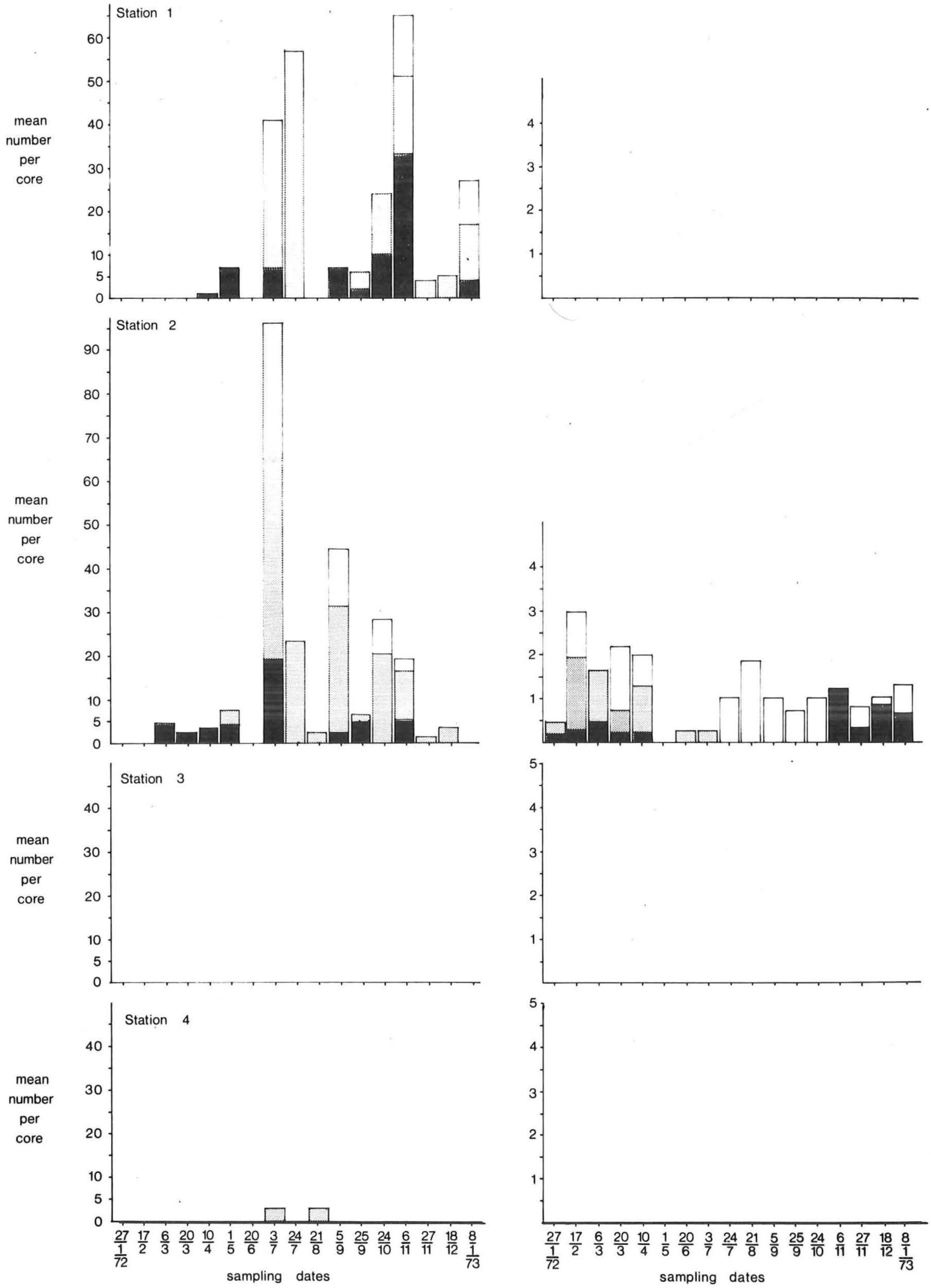
Throughout autumn and winter isopods increased in size and by August females were gravid. Embryos were carried beneath the abdomen until spring when they were released. Austridotea annectens is an active swimmer and was observed in the water column. Individuals rested frequently on the downstream side of large pebbles and appeared to forage in "dead" spaces amongst the shingle. It does not appear to be tolerant of fine sediment or organic enrichment of the water and these two factors presumably contribute to its restricted distribution.

Paracalliope fluviatilis (Thomson) (Figure 17)

Amphipods were found at Station 1 and 2 and occasionally at Station 4 but were absent from Station 3. Numbers fluctuated throughout the year, but were greatest in spring and

FIGURE 17: Mean numbers of Paracalliope fluviatilis (left) found at four stations in the Leeston drain between 27/1/72 and 8/1/73 (non shaded = >3 mm, light shaded = $>1.5 < 3$ mm, dark shaded = <1.5 mm)

Mean numbers of Austridotea annectens (right) found at four stations in the Leeston drain between 27/1/72 and 8/1/73 (non shaded = >80 mm, light shaded = $> 20 < 80$ mm, dark shaded = <20 mm).



Station 1
Station 2
Station 3
Station 4
mean number per core
27/1/72 17/2 6/3 20/3 10/4 1/5 20/6 3/7 24/7 21/8 5/9 25/9 24/10 6/11 27/11 18/12 8/1/73
sampling dates

summer when most of the animals collected were small (less than 1.5 mm long) and medium sized (less than 3 mm). It was not until late spring and early summer that large individuals (greater than 3 mm) were collected and they were always in low numbers (3-5/sample). At times (3 July and 6 November), exceptionally high numbers of small and medium sized amphipods were collected. Those taken in November were part of a mass upstream migration being made by this species, but large scale upstream movements were not found at other times of the year and could not account for the high numbers found in July. During the migration, huge numbers of P. fluviatilis were observed swimming and walking over the substrate particularly in the slower water at the sides of the stream. At other times of the year animals were found on and between sediment particles and were spread evenly across the width of the stream bed.

Burnet (1969), Fowles (1972) and Hirsch (1958) noted that this species had a preference for overhanging grass banks and aquatic weed beds rather than shingle as habitats. The absence of weed beds in the Leeston drain may have forced this species into this benthic habitat, and indicates that it is somewhat facultative in its habitat selection. It is, also, able to tolerate a limited amount of pollution as it was found at Station 1 although not at Station 3. It is possible that the nutrient loading of the water rather than the substrate modification limited its distribution.

Coleoptera:

Elmidae (Figure 15)

Elmid larvae were found mainly in the cleaner waters of Stations 2 and 4 where they were collected in small numbers (2-5/sample). Their distribution was thus generally confined to the swifter flowing waters of the drain where larger sediments were found. There is little published information on the New Zealand Elmidae but it does appear that the habitat preferences vary as Allen (1951) noted a quiet water preference whereas, Marples (1962) and Stout (1969) noted a preference for swifter waters. A single adult beetle was collected during the summer at Station 2.

6.3 Quantitative Composition of Benthic Fauna

The preceding section has dealt with only 15 of the species (Table 25) found in the exposed shingle substrates of the Leeston drain. Whereas, in this section the whole fauna is considered.

6.4 Total Population Densities (Figure 18)

The fauna have been divided into four groups for convenience, as follows:-

1 Oligochaetes; 15 species

2 Molluscs; four species

3 Insects; larvae of 11 species

4 Others; Platyhelminthes, Nematoda and Crustacea

At Stations 1 and 2 fluctuations in mean numbers ranged between 17 and 582 animals per sample. More animals were present at Station 1 at most times. Station 3 lacked the marked seasonal fluctuations found elsewhere and

TABLE 25: Faunal list for the shingle areas of the Leeston drain.

Platyhelminthes

Cura pinguis (Weiss)

Oligochaeta

Stylodrilus heringianus Claparède

Lumbriculus variegatus (Müller)

Haplotaxidae

Chaetogaster sp.

Pristina sp.

Nais variabilis Piguet

Nais elinguis Müller

Slavina appendiculata (Udekem)

Telmatodrilus multiprostatus Brinkhurst

Aulodrilus pluriseta (Piguet)

Tubifex tubifex (Müller)

Potamothrix bavaricus (Öschmann)

Limnodrilus udekemianus Claparède

Limnodrilus hoffmeisteri Claparède

Eiseniella tetraedra (Savigny)

Nematoda

Mollusca

Potamopyrgus antipodarum (Gray)

Physa sp.

Gyraulus corinna (Gray)

Sphaerium novaezelandiae Deshayes

Crustacea

Austridotea annectens Nicholls

Paracalliope fluviatilis (Thomson)

Insecta

Deleatidium sp.

Psilochorema bidens McFarlane

Hydropsyche colonica McLachlan

Pycnocentrodes aureola (McLachlan)

Hudsonema amabilis (McLachlan)

Oxyethira albiceps (McLachlan)

Muscidae

Chironomus zealandicus Hudson

Orthocladine sp.

Ceratopogonidae

Elmidae

supported the greatest numbers of animals which ranged between 201 and 794 per sample. Lowest densities occurred at Station 4 (maximum number of animals/sample was 121). This was primarily due to the low number of oligochaetes present there.

The relative contribution of the four faunal groups varied between stations. Few insects occurred at Station 3 but there were close similarities between the fauna at Stations 1 and 2 in spite of the fact that Station 1 has an increased nutrient and fine sediment loading. Some of the insect species found at Station 2 were eliminated by this alteration and the finer sediment allowed inhabitation by a greater number of oligochaetes. There was no increase in numbers of <u>Potamopyrgus antipodarum</u> at Station 1 as found at polluted Station 3, but, numbers of sediment dwelling <u>Sphaerium novaezelandiae</u> were greater than at Station 2.

Station 2 was unpolluted and supported the greatest number of species (19) whereas 15 were found at Station 1 below the cowshed outfall. Fewest species were found at Station~~s~~ 3 (11) where pollution was most marked. Most of the species occurring at Station 3 were oligochaetes and molluscs. At Station 4 the fauna was similar to that of Station 2 although with fewer oligochaetes as the substrate conditions were less suitable. The number of species present at this station was 16.

FIGURE 18: Mean total population densities at four stations in the Leeston drain between 27/1/72 and 8/1/73. (upper non shaded = oligochaetes, lightly shaded = molluscs, darkly shaded = insects, lower non shaded = 'others').

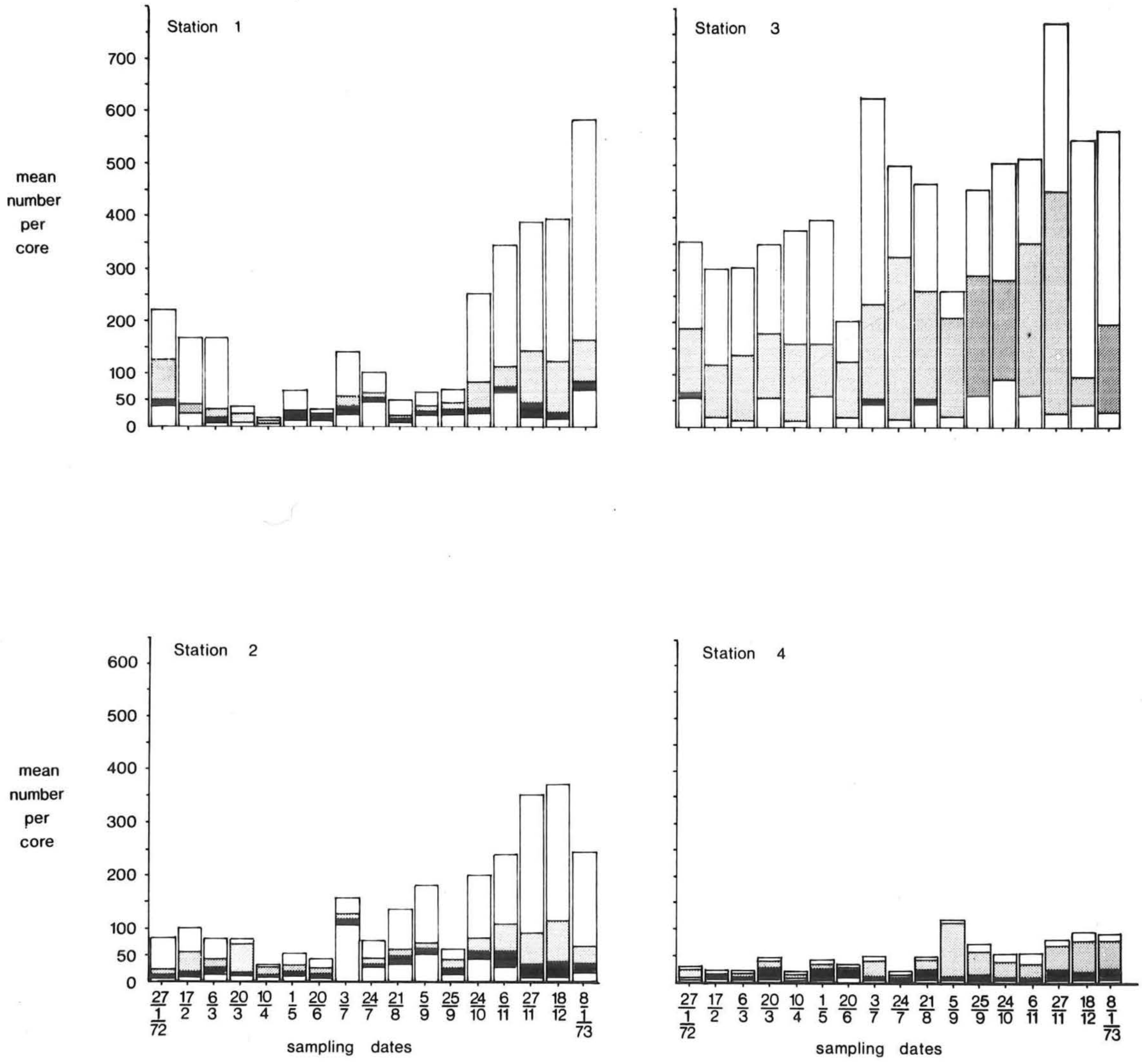
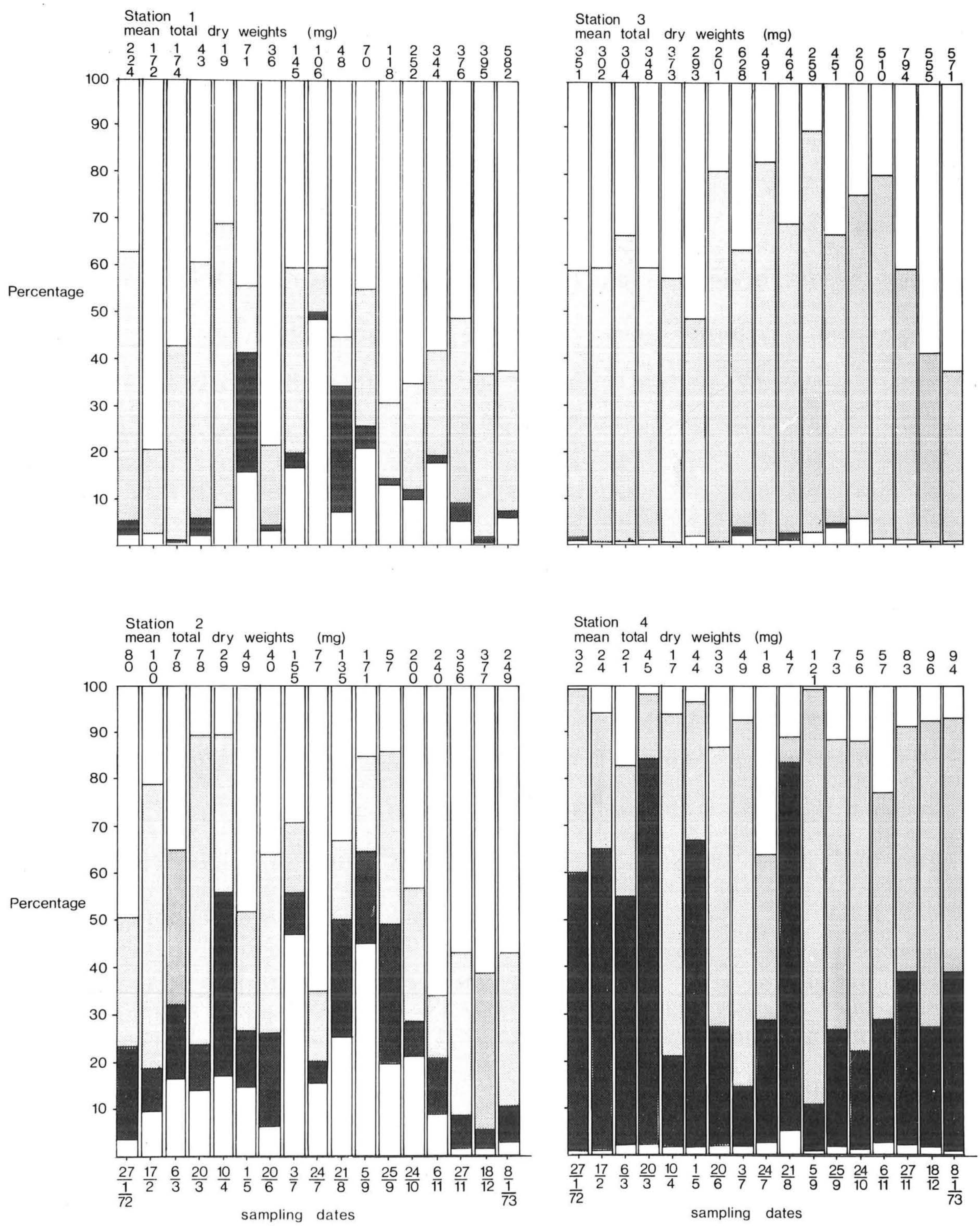

Station 1
Station 3
Station 2
Station 4
mean number per core
0
50
100
200
300
400
500
600
700
27/1/72
17/2
6/3
20/3
10/4
1/5
20/6
3/7
24/7
21/8
5/9
25/9
24/10
6/11
27/11
18/12
8/1/73
sampling dates

FIGURE 19: Percent composition of total standing crop at four stations in the Leeston drain between 27/1/72 and 8/1/73.
(upper non shaded = oligochaetes
lightly shaded = molluscs
darkly shaded = insects
lower non shaded = 'others').


Station 1
mean total dry weights (mg)
224 172 174 43 19 71 36 145 106 48 70 118 252 344 376 395 582
Station 3
mean total dry weights (mg)
351 302 304 348 373 293 201 628 491 464 259 451 200 510 794 555 571
Station 2
mean total dry weights (mg)
80 100 78 78 29 49 40 155 77 135 171 57 200 240 356 377 249
Station 4
mean total dry weights (mg)
32 24 21 45 17 44 33 49 18 47 121 73 56 57 83 96 94
Percentage
100
90
80
70
60
50
40
30
20
10
27/1/72 17/2 6/3 20/3 10/4 1/5 20/6 3/7 24/7 21/8 5/9 25/9 24/10 6/11 27/11 18/12 8/1/73
sampling dates

6.5 Total Standing Crop (Figure 19)

Station 1: The total standing crop (TSC) at Station 1 varied between 19 and 582 mg per sample. Highest values occurred in late spring - early summer and the lowest in late autumn - early winter. Oligochaetes made up the greatest percentage of the TSC with a mean annual contribution of 54.5%. The mean contribution of molluscs to the TSC was about 20% less than that of the oligochaetes with Potamopyrgus antipodarum providing the greatest mean annual biomass. However, in spring Sphaerium novaezelandiae provided the major contribution.

The mean contribution of insects to the TSC was 16.5%. Their maximum contribution of 25 to 27% occurred during winter and was largely contributed by Pycnocentrodes aureola, Oxyethira albiceps and a species of Orthocladiinae. "Other" taxa contributed only 11% to the TSC, Cura pinguis and Paracalliope fluviatilis making the greatest contribution in this group. Nematodes which were present in high numbers at this station made little impact on the biomass and never exceeded 1.4 mg per sample.

Station 2: The mean annual TSC was lower than at Station 1. The lowest TSC of 29 mg per sample occurred in autumn whereas the highest value, 377 mg was found in December. The relative contributions of the four faunal groups differed from those found at Station 1, the importance of oligochaetes being reduced whereas the "other" groups increased in importance. The two crustaceans, Austridotea annectens and P. fluviatilis were particularly important and the presence of large numbers of *P. fluviatilis* in the 3 July and 5 October samples were responsible for unusually high standing crop values (96 and 46 mg) respectively. In general, the TSC was more evenly divided between the different taxa than at Station 1.

Station 3: This station had a distinctively different species composition from the other stations with the TSC being dominated by molluscs which contributed a mean of 62% of the TSC. The total standing crop was highest at this station and ranged between 200 and 794 mg per sample. There were no clear seasonal fluctuations in TSC but the highest values were collected in late spring. Although molluscs dominated the biomass on an annual basis their contribution varied seasonally. During winter, molluscs were the dominant group and their biomass was produced mainly by medium and large individuals of *P. antipodarum*.

In spring, many small snails contributed to and maintained a high standing crop. A decline in molluscan dominance occurred towards the end of spring when numbers of *P. antipodarum* declined. At this time, oligochaetes were most abundant, their body weights were high, and they represented the major group in terms of TSC. Oligochaete biomass at Station 3 was in excess of that found at any other station. Unlike Station 2 this biomass was produced mainly by four species, *L. variegatus*, *T. tubifex*, *P. bavaricus* and *L. hoffmeisteri*. Insects and other taxa including nematodes which occurred in large numbers made little contribution to the TSC.

Station 4: Total standing crop at this upstream station was superficially similar to that at Station 2 except that the contribution of oligochaetes was reduced and the insect and molluscan groups were co-dominant. Mean monthly TSC's were the lowest found and ranged between 17 and 121 mg per sample. The molluscan group was made up of *P. antipodarum* and *Physa* sp. which ~~and~~ had its greatest abundance at this station.

The low standing crop of oligochaetes was related to the coarse substrate present and most of the oligochaete standing crop was provided by the large lumbricid, *Eiseniella tetraedra* which tends to favour coarser sediments. In the clean-water conditions found at this station, insects made their greatest contribution (39%) to the total biomass. Species found were similar to those occurring at Station 2 except that *Hydropsyche colonica* and *Psilochorema bidens*, both relatively large insects, with mean dry weights of 5.8 mg and 2.9 mg respectively were also common. The biomass of the "other" taxa was insignificant and was produced mainly by small numbers of *Cura pinguis*.

From these results it is apparent that in cleaner conditions biomass is more regularly distributed between faunal groups. On the other hand, enriched areas support greater TSC's which are produced by fewer species with greater numbers.

7 SPECIES DIVERSITY

7.1 Introduction

The preceding sections of this thesis have presented information obtained from the benthic survey on individual species, total numbers of animals and their biomasses but have not provided a concise measure of community structure.

Community structure can be described in terms of species frequency, species per unit area, spatial distribution of individuals, and numerical abundance of species (Hairston 1959). Species diversity, as it is a function of the number of species present and the eveness with which the individuals are distributed among the species present, has been used as a means of summarising community structure. A number of papers have utilised diversity indices to characterise the community structure of an area, examples of freshwater studies being the works of Harrel and Dorris (1968), Ransom and Dorris (1972), Wilhm (1970) and Wilhm and Dorris (1966; 1968).

Differences in the community structure reflect differences in environmental conditions and these are indicated by changes in the diversity index. Thus measurements of diversity can be used to evaluate the degree of pollution in streams (Wilhm 1972).

In New Zealand, a limited number of published and unpublished reports contain species diversity measurements obtained from clean and polluted waters (Bennington 1971, Fowles 1971; 1972, Lear 1972, McCammon 1972, Winterbourn et al. 1971). In this section a species diversity index is used to compare the benthic communities found at the four stations in the Leeston drain and its value as a method for detecting organic pollution in streams is discussed.

7.2 Methods

Shannon's index (Shannon 1948),

$$H = -\sum (P_i \log P_i)$$

or after substitution of the uncertainty symbol H with the diversity symbol $\bar{d}$ (Wilhm 1972)

$$\bar{d} = -\sum \left[(n_i/n) \log_2 (n_i/n)\right]$$

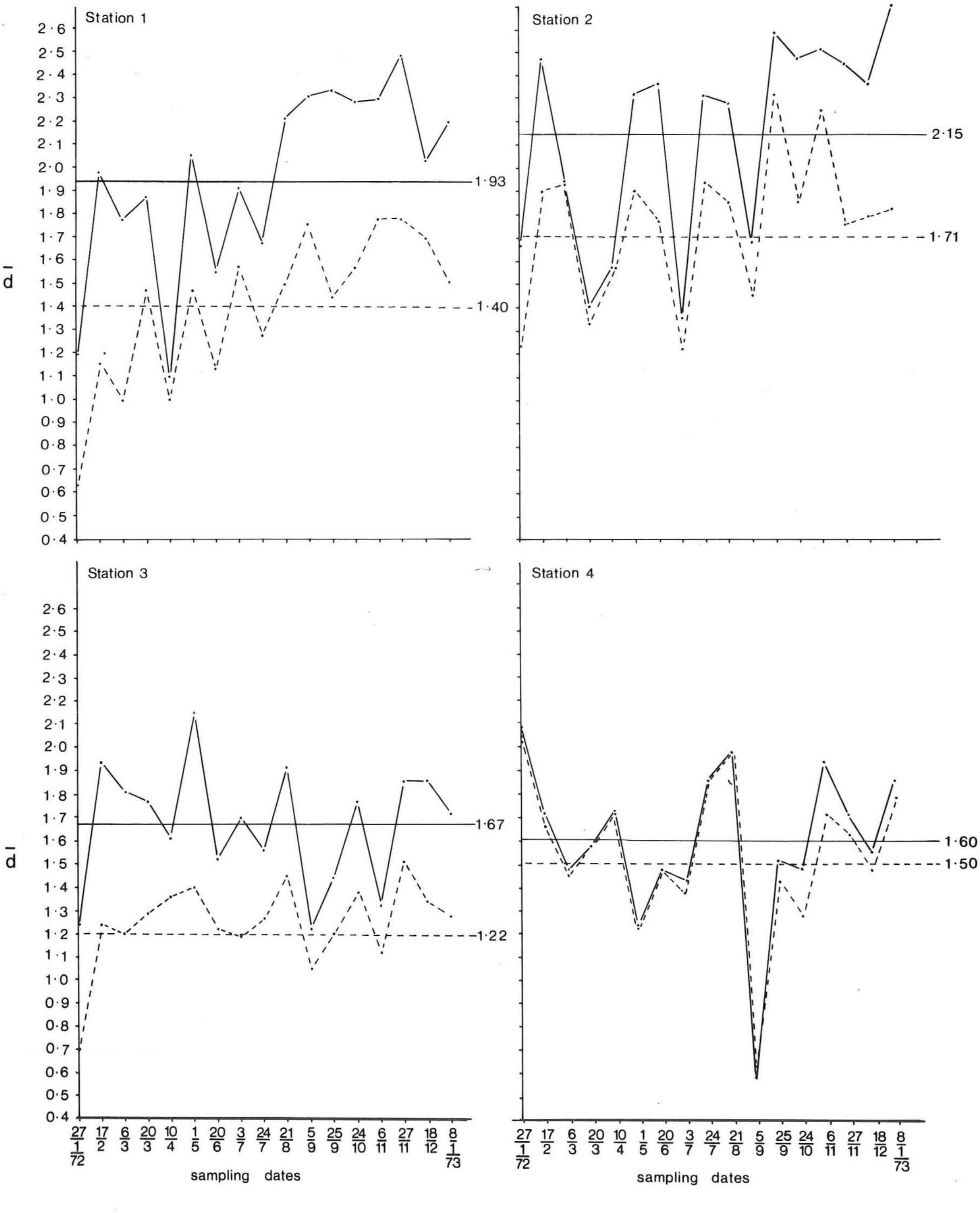
was used because of its relative independence of sample size and because it considers both species numbers and the distribution of individuals among the species.

Analyses were performed for each station on each sampling date, the sum of all species and individuals from the five replicate samples taken at each station being used in the calculations. Nematodes were not included.

7.3 Results and Discussion

Diversity at all stations fluctuated between sampling dates (Figure 20). Stations 1 and 2 showed an increase in diversity in spring and summer but no seasonal trends were apparent at Stations 3 and 4. Mean annual diversity for the four stations is also shown in the same figure. The highest mean diversity (2.15) ~~being~~ was found at Station 2, the area with the least stream bed alteration or pollution.

FIGURE 20: Mean seasonal diversity ($\bar{d}$) at four stations in the Leeston drain between 27/1/72 and 8/1/73. (Solid line represents results of complete species list calculation, dotted line represents results of 'lumped' oligochaete calculations).



Station 1
Station 2
Station 3
Station 4
d.I
1·93
1·40
2·15
1·71
1·67
1·22
1·60
1·50
sampling dates

Station 1 had the second highest mean diversity value, 1.93. The reduction from the Station 2 value was the result of changes in the stream environment caused mainly by the presence of dairy shed wastes. These changes resulted in the exclusion of some of the less tolerant species and an increase in the numbers of individuals belonging to some of the more tolerant species. Station 3 had the most polluted environment and a low mean species diversity of 1.67 was produced by large numbers of relatively few pollution tolerant species. Station 4, a clean water station had a mean diversity index of 1.60. This situation which appears anomolous at first glance resulted from the presence of low total numbers of relatively few clean water species, associated with large numbers of *Potamopyrgus antipodarum*. The small number of species found was the result of the stream bed consisting of coarse sediments on a hard clay pan which could not support many species of oligochaetes as did the other stations where fine sediments also occurred.

The finding of similar species diversities at a polluted and a clean station (3 and 4) indicates the necessity of having detailed information on the physical factors influencing the community structure, and makes it essential that these factors are taken into account when interpreting diversity values. It is also important that all animals must be separated at the species level or at least into groups of the same taxonomic level. This has not always been done and an examination of some of the calculations made in New Zealand stream studies shows that the Oligochaeta as a group generally have been lumped into three families, Lumbriculidae, Tubificidae and Naididae. In view of the fact that 15 species of oligochaetes were identified during the present study it is clear that such lumping could produce highly aberrant results. To test this contention the oligochaete data obtained in the present study were lumped into the three families listed above and species diversity at each station was recalculated. Results are shown in Figure 20.

The effect of lumping made a greater distinction (Figure 20) between the polluted and non polluted stations as it reduced the total number of species and allocated a high proportion of the total fauna to the three composite groups. At the polluted stations where oligochaete species were dominant lumping reduced species diversity whereas at unpolluted stations reduction in the diversity index was less as oligochaetes were not the dominant species. The diversity values obtained at Station 2 were not as high as some overseas values obtained with Shannon's index (2.6 to 4.0) nor were values at the polluted Stations 1 and 3 as low as some overseas values (0.42) (Wilhm 1972).

Diversity values calculated for some other rivers in the Canterbury region (Table 26) cannot be compared directly with those of the Leeston drain as they have been calculated with Margalef's (1968) or Brillouin's (1963) formulae and the oligochaetes in the samples have been lumped. In addition most of the samples were collected with a Surber sampler and hence were of a different size.

TABLE 26: Maximum and minimum diversity values obtained in some Canterbury rivers.

			Index	Maximum (Clean)	Minimum (Polluted)
Bennington	(1971)	Kaiapoi	Brillouin	1.6	0.7
Fowles	(1971)	Cam River	Margalef	1.43	0.33
Winterbourn *et al*.	(1971)	Waimakariri River	Margalef	3.87	0.34
Fowles	(1972)	South Branch Waimakariri River	Margalef	2.46	-
McCammon	(1972)	Styx River	Margalef	2.1	0.32

In this study species diversity measurements have been used to provide a measure of the community structure of the stream and to examine the effects of organic pollution on the benthic fauna. It has been demonstrated that care must be taken when interpreting the effects of pollution and diversity as different environmental conditions unrelated to pollution can produce diversity values that are comparable to those in obviously polluted areas. To avoid possible misinterpretation, diversity measurements must be used in conjunction with relevant environmental data.

SECTION B

FIELD EXPERIMENTS

8 GROWTH OF TWO OLIGOCHAETES : A FIELD EXPERIMENT

8.1 Introduction

In the preceding chapter changes in the composition, density and biomass of the fauna were examined in relation to eutrophication of the stream, and it was shown that a number of the species that occur in polluted situations were present in very high numbers. Many of these were oligochaete species which are known to be resistant to extremely adverse conditions (Palmer 1968). For this reason they make ideal experimental animals but partly because of the difficulties in species identification they have been neglected in the past. The pioneering work of Brinkhurst culminating in the publication of a large monograph by Brinkhurst and Jamieson (1971) has largely rectified the identification problem, and as a result more experimental studies on oligochaetes have been produced in recent years (Appleby and Brinkhurst 1970; Aston 1968; 1973; Brinkhurst <u>et al</u>. 1972; Brinkhurst and Kennedy 1965; Kennedy 1966; Ladle 1971; Warve and Brinkhurst 1971.) Most of these experimental studies have been carried out in small containers of aerated mud in laboratory situations and although attempts have been made to relate findings to field conditions no attempts have been made to carry out field experiments.

8.2 Methods and Materials

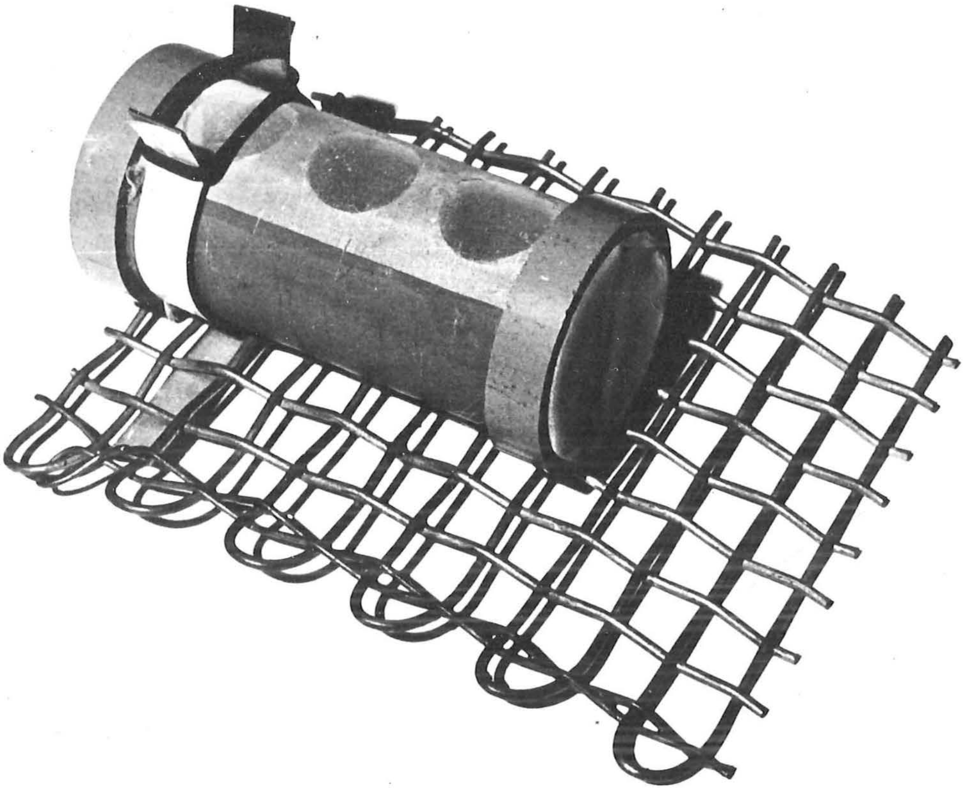
The aim of this experiment was to examine the relative growth rates, maturation periods and changes in worm biomass of two species of oligochaete in different sized sediments and at different productivity levels. The term productivity is used in a qualitative sense to describe broad differences between stream sites as indicated by aquatic macrophytes, algae, B.O.D. measurements and the numbers and biomass of animals present.

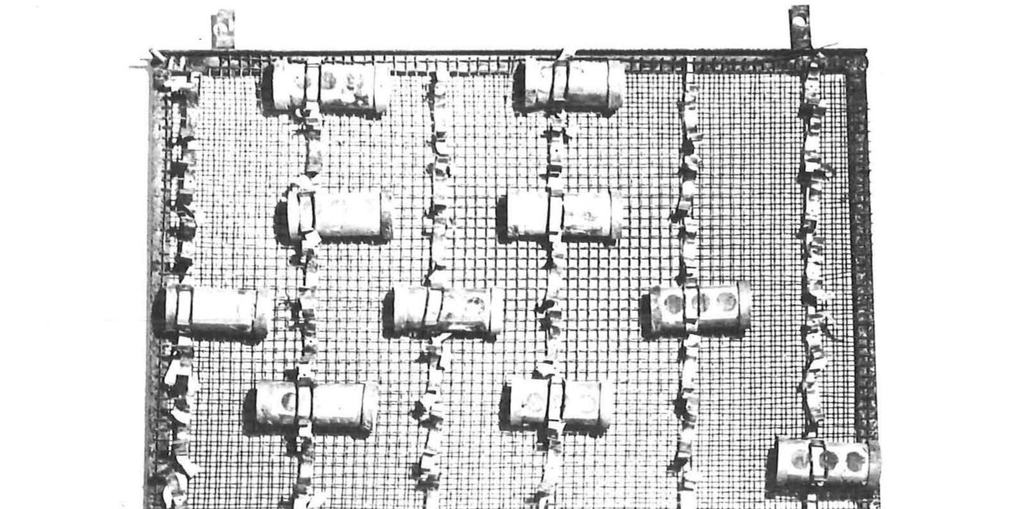
One hundred experimental containers, constructed from 120 mm long sections of 42 mm diameter, grey PVC pipe, a durable, easily worked non-toxic material (Plate 12). Nylon mesh (150 µm) was placed over the ends of each tube and held in place by a PVC ring (Plate 12). Pieces of mesh were glued with PVC glue over three 20 mm holes drilled in the upper surface of each tube. This mesh size was chosen to allow water to flow through the tubes but ensure that worms were retained. Containers were numbered, located randomly on a holding grid (Plate 12) and placed in the stream at Station 3 (high productivity) and Station 4 (low productivity).

Sediments used were obtained by sieving river shingle through a series of "Endecott" sieves. The upper size limit of fine sediment particles was 180 µm whereas coarse sediment particles ranged from 180 - 710 µm. To simulate naturally occurring fine sediments, 13% dry weight of organic material was added. One percent dry weight of organic material was added to coarse sediments. Organic material was collected from a bog at the edge of the Leeston drain, dried at 100°C for three days, broken down and sieved into two size classes as for sediments. To supply the dried sediment with a population of micro-organisms it was inoculated with muddy stream

PLATE 12: An experimental container showing details of construction (top) and holding frame for positioning experimental containers in the Leeston drain (bottom).

(photo: J.W. Marshall).





water.

Seventy five grams of wet coarse sediment were placed in each of 48 containers and a similar weight of wet, fine sediment was placed in a second set. Containers were placed in an artificial stream for five days to allow micro-organisms to colonise the sediment. At the end of this time five tubes were emptied and the sediment was dried and sieved to determine whether any had been lost. Almost all (97 %) of the material was recovered.

The oligochaetes used in the study were Tubifex tubifex and Lumbriculus variegatus both of which were common at most stream stations. Mature specimens of T. tubifex i.e. with well developed clitellum were collected from the Leeston drain.

Tubifex tubifex has a well developed sexual reproduction cycle and lays white cocoons 1 mm long which hatch in approximately 20 - 22 days at 15°C under laboratory conditions. In contrast to this L. variegatus has rarely been seen in a sexually mature state and its normal mode of reproduction is by asexual division. The resulting "bits" grow new anterior or posterior segments. Mature specimens of L. variegatus were obtained from a stock maintained in the Zoology Department of the University of Canterbury. The criteria used to indicate maturity were large size (length 60 to 100 mm), and absence of regenerating segments or fission zones. Twenty specimens of each species were placed in each of 24 containers of each sediment size. The number of worms selected approximated natural field densities.

The 48 containers containing each species allowed four samplings, consisting of three replicates of each treatment, to be made at two monthly intervals, starting in August 1972.

From each container all sediments were collected and retained for analysis. Cocoons and worms were hand picked from the mud and the latter were placed in vials of pond water for 24 hours to void gut contents, after which they were anaesthetised with carbon dioxide saturated water, and sorted into maturity and size classes.

Tubifex tubifex was divided into three groups:

1 Mature - genital segments developed; clitellum present

2 Immature - length greater than 5 mm; no genitalia

3 Young - length less than 5 mm; yoke cells present in gut.

Lumbriculus variegatus was divided into:

1 Mature worms and worms not exhibiting regenerating segments

2 Regenerating worms i.e. exhibiting regenerating segments.

All worms from each vial were placed on pre-weighed glass fibre filters, dried and ashed to determine ash free dry weight (AFDW). Cocoons of *T. tubifex* were counted and the number and state of development of eggs in the cocoons were noted. Cocoons were divided into two classes, small (less than 1 mm long) and large (greater than 1 mm long). Ash free dry weights were determined on samples of 50 cocoons from each class.

8.3 Results

Tubifex tubifex

Numbers: The greatest increase in numbers of worms occurred in fine sediment - high productivity (FH). This was the result of a long cocoon production period combined with high egg numbers per cocoon and apparently lower mortality in the later months of development. It is notable that this was the only set in which worms derived from cocoons laid during the eight month experimental period matured and laid a new set of cocoons (Figure 21). The number of worms which developed in fine sediment-low productivity (FL) was much lower than in FH. In this set a much shorter period of cocoon production occurred and a lower number of eggs per cocoon was found.

In both coarse sediment sets fewer worms developed than in fine sediments. The higher numbers found in coarse sediment-high productivity (CH) compared with coarse sediment - low productivity (CL) was partially the result of a longer period of cocoon production and a higher mean number of eggs per cocoon in the former (7 c.f. 3). The rate of increase in numbers of worms produced was similar in the two sets but CH was able to sustain this rate of increase longer.

Biomass: Increase in ash free dry weight (Figure 22) was highest and most rapid in the fine sediment - high productivity situation. Under these conditions worms attained a final mean biomass per container of 37.5 mg and growth showed no signs of levelling off after eight months. In the coarse sediment - high productivity situation a continuous increase in biomass was also found over eight months but growth was not as fast nor as great, and reached only 7.5 mg at the end

FIGURE 21: Rate of increase of Tubifex tubifex numbers, over eight months, under different environmental conditions.

Key: FH = fine sediment high productivity
FL = fine sediment low productivity
CH = coarse sediment high productivity
CL = coarse sediment low productivity.

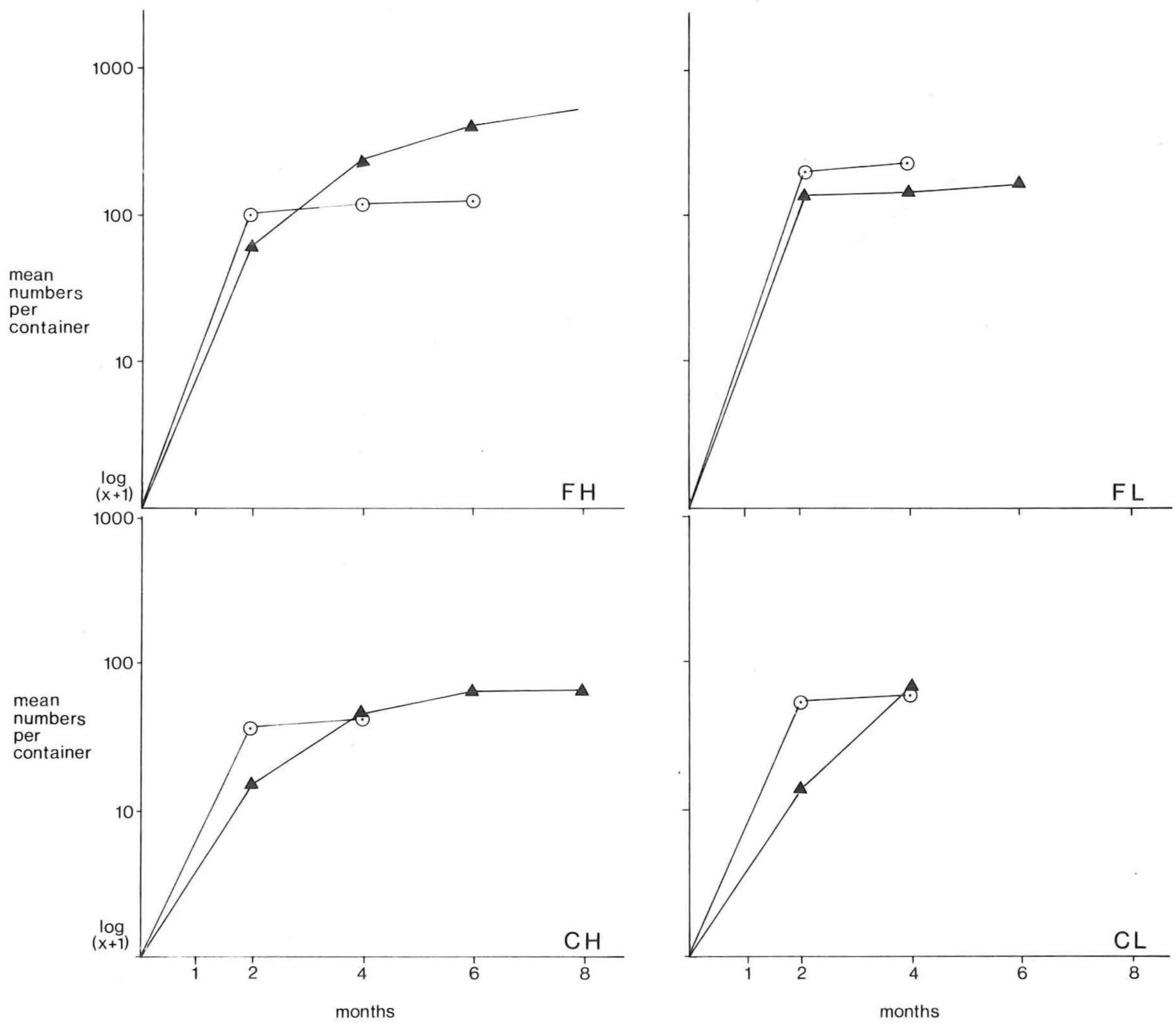
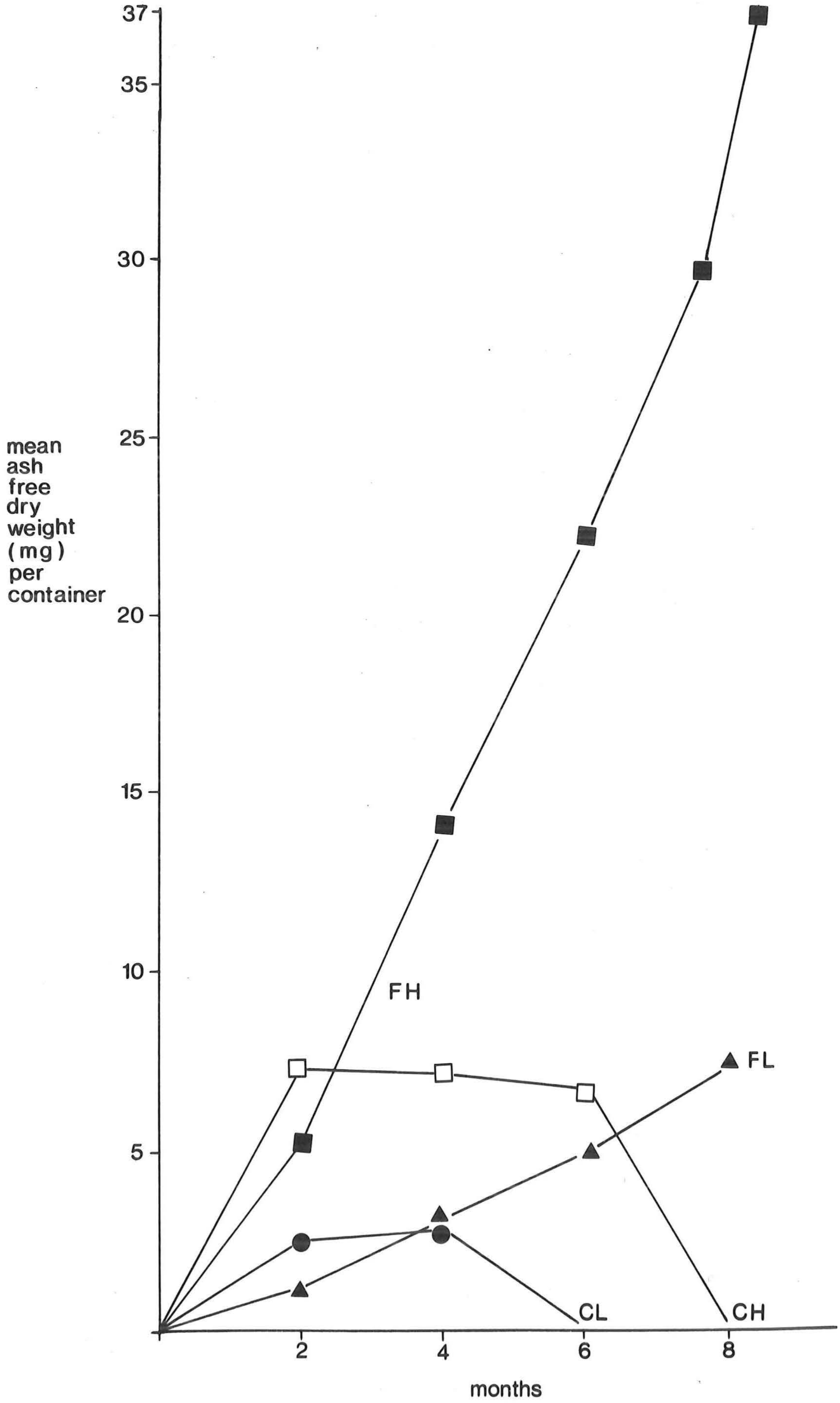

1000
100
10
mean numbers per container
log (x+1)
FH
FL
CH
CL
1
2
4
6
8
months

FIGURE 22: Rate of increase over eight months of *Tubifex tubifex* biomass (mg ash free dry weight) under different environmental conditions.

Key: FH = fine sediment high productivity
FL = fine sediment low productivity
CH = coarse sediment high productivity
CL = coarse sediment low productivity.


37
35
30
25
20
15
10
5
mean
ash
free
dry
weight
(mg)
per
container
FH
FL
CL
CH
2
4
6
8
months

of the period. The fine sediment - low productivity set showed an increase in AFDW similar to that found in FH but the maximum biomass attained was only 7.5 mg. This occurred in the second month after which population biomass slowly declined until by the eighth month all worms had died.

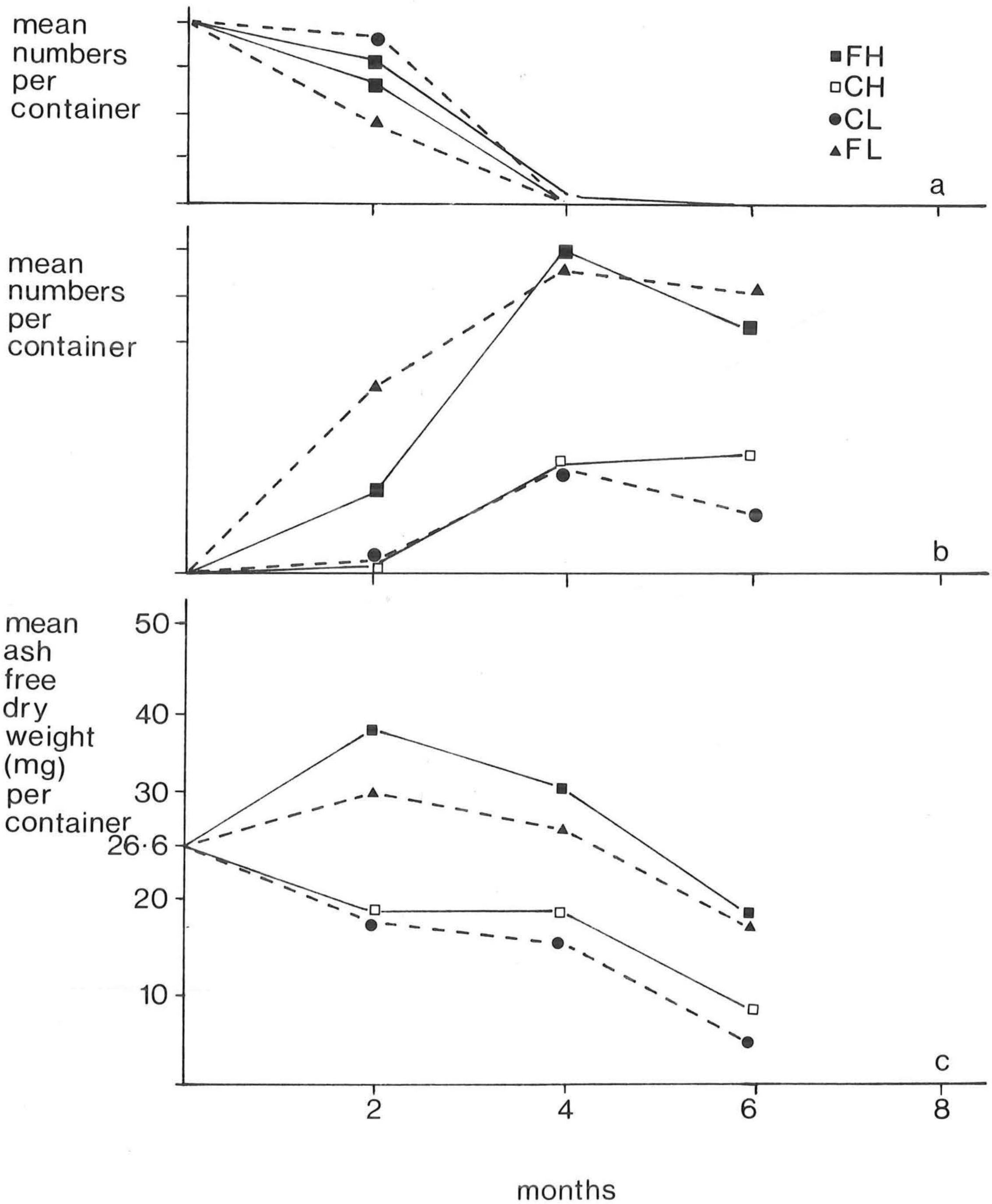
A situation similar to that found in FL was also found in CL, but the maximum AFDW reached was only 3.5 mg. This was attained after two months and maintained until month four, but by month six all the worms had died.

Lumbriculus variegatus

Numbers: The rate of asexual reproduction of *L. variegatus* was faster in the two fine sediment combinations (Figure 23) and by the fourth month no whole worms remained. The regeneration rate of worms was the reciprocal of this and by the fourth month two regeneration cycles had been completed with only low mortality. In contrast, worms kept in coarse sediments were slower to divide and in CL small numbers of whole worms remained throughout the first six months of the experiment. Also, the mean number of regenerating worms present at the end of the experiment was much lower as a result of high mortality. Mortality of anterior regenerating "bits" was greater than that of posterior regenerating "bits" (Table 27) although in the fine sediments mortality of anterior segments was lower than in coarse sediments.

Biomass: The increase in ash free dry weight of *L. variegatus* was quite different from that found for *T. tubifex* (Figure 22). In the first two months the mean AFDW of FH worms increased by 22 mg and in FL by 7 mg.

FIGURE 23: (a) Mean numbers of *Lumbriculus variegatus* and of
(b) regenerating *L. variegatus* and
(c) mean ash free dry weight of *L. variegatus* per container over eight months.


mean numbers per container
FH
CH
CL
FL
a
mean numbers per container
b
mean ash free dry weight (mg) per container
50
40
30
26·6
20
10
c
2
4
6
8
months

However, after these initial increases, biomass declined. In coarse sediments a decline in total biomass occurred from the outset of the experiment.

TABLE 27: Mean numbers of regenerating posterior and anterior segments of <u>Lumbriculus variegatus</u> found during the experimental period (W = whole; R = regenerating).

Months	0		2		4		6	
Treatments	W	R	W	R	W	R	W	R
FH	20	0	12	6	42	28	38	16
FL	20	0	32	8	39	21	41	11
CH	20	0	1	0	18	7	24	3
CL	20	0	1	1	20	3	13	0

8.4 Discussion

The experimental results suggest that production of <u>T. tubifex</u> is partially determined by sediment size. This is indicated by the different growth rates and biomasses attained by animals in fine and coarse sediments at each station, and by the very small difference in growth rates found in high and low production areas for each sediment type.

Maximum biomass of worm populations held in low productivity waters was reached after two months, this upper limit being related to and perhaps determined by sediment size. However, as population biomass continued to increase throughout the eight month period in high productivity waters it is clear that population growth is not determined solely by sediment size. Another factor which could influence growth is the amount of organic material present in the sediment. However, this did not appear to be utilised significantly by the animals, as in all containers the organic content of the sediments did not change more than 1% during the experimental period. A similar insignificant reduction in percent organic matter was noted by Brinkhurst et al. (1972). If the organic fractions were being utilised by the worms one might expect the populations in FH and FL to have similar growth rates; this was not the case. The possibility that organic matter is utilised by the worms and rapidly recycled within the sediments can probably be disregarded for the same reason.

The most likely energy source for the worms is the microflora in the sediment as indicated by the work of Brinkhurst and Chua (1969), Coler et al.(1967), and Warve and Brinkhurst (1971) who have shown that worms feed on bacteria and exhibit selective assimilation of the bacteria they ingest. Although sediment microflora was not examined in this study it seems likely that differences in microbial activity are found between the two experimental areas in the Leeston drain. One indication of this is given by the differences in biochemical oxygen demand (B.O.D.) of stream water found at the two sites (Figure 5).

The high productivity area had a mean B.O.D. value over the experimental period of 4 g/m^3 whereas the value in the low productivity area was only 1 g/m^3.

The experiments with *L. variegatus* were less successful as the populations did not maintain themselves in any of the four treatments. The reasons for this are unclear.

However, in the first two months *L. variegatus* responded in a similar way to *T. tubifex* with growth and reproduction being greatest in fine sediments and high productivity conditions.

The results of this field experiment indicate that the greatest numbers and biomass of *T. tubifex* are produced in fine sediments and under high productivity conditions where a long breeding period can occur and large numbers of cocoons are produced.

Towards the end of the field experiment numbers of *T. tubifex* in low productivity areas (and all *L. variegatus* combinations) had declined. A possible mechanism to account for this die-off has been put forward by Warve and Brinkhurst (1971) who noted that when a single species of oligochaete is kept in an experimental situation it can, by selective feeding, reduce the number of bacterial species in a sediment to a few or even one, at which time the worm population dies. This could have happened in this experiment as feeding pressures would undoubtedly have increased as a result of the initial rapid increases in worm numbers. Experimentation with a single species in small amounts of sediment may therefore have adversely affected the increase in biomass. In contrast to this, Brinkhurst *et al.* (1972) found that a mixed culture of oligochaete species in 400 g of sediment produced a greater combined biomass than the sum of the same individuals in pure culture. Their findings combined with the results of the present experiments suggest that in order to obtain realistic results, long term experiments (i.e. greater than about two months) cannot be usefully carried out in highly simplified ecosystems.

8.5 Conclusion

Results of a field experiment indicated that a higher biomass of T. tubifex could be obtained in fine sediments than in coarse sediments. The reason for this may be the greater surface area available for microbial colonisation in fine sediments.

In low productivity areas, levels of microbial production may be insufficient to support and maintain such rapidly increasing worm populations as in higher productivity areas.

9 PRIMARY PRODUCTION ON ARTIFICIAL SUBSTRATES

9.1 Introduction

The benthic algae or 'periphyton' in streams often make significant contributions to the primary production of an area. To examine the periphyton it must be removed from the stream and artificial substrates have been employed for many years to collect it (Naumann 1915, quoted by Cooke 1956). Cooke (1956) collated and reviewed techniques for the examination of various organisms that attached themselves to artificial substrates and was followed a year later by Lund and Talling (1957) who described methods available for the study of benthic algae. Cooke, Lund and Talling stated that the methodological literature was immense, and it has continued to proliferate to the present day.

Castenholz (1961) in his evaluation of glass substrates made an important contribution when he showed the effect that orientation of the substrate had on algal growth. He demonstrated that the flora developed better on horizontal plates than vertical ones and usually consisted of a more natural assemblage of algae. Sladeckova (1962) discussed methods for investigating "Aufwuchs" or periphyton communities and presented a critical evaluation of techniques for the determination of periphyton biomass.

Wetzel (1964) examined methods for the quantitative examination of periphyton and gave an interesting account of the terminology used in attached algal studies, and a year later, he (Wetzel 1965), reviewed methods for studying primary productivity of higher aquatic plants and periphyton and outlined some of the problems inherent in the use of artificial substrates. Recently, Kevern et al. (1966) investigated the productivity of periphyton on artificial substrates in a laboratory stream and by applying a discontinuous linear regression model to the growth curve they were able to distinguish two growth phases; an initial lag phase and an exponential growth phase.

The use of chlorophyll a measurements to estimate production and (standing crop) of periphyton was first used in phytoplankton studies by Manning and Juday (1941), and later by Edmondson (1956) and Ryther (1956). In 1959, McConnel and Sigler applied the chlorophyll extraction method to a lotic situation and concluded that algal biomass and production could be determined from chlorophyll measurements. Grzenda and Brehmer (1960) working in the Red Cedar River (Michigan) extracted chlorophyll with ethanol and related the chlorophyll levels to the weight of organic material on the substrate. Subsequently, Waters (1961) measured the amount of chlorophyll in stabilised periphyton communities on concrete cylinders placed in a stream, and found that the algae on these artificial substrates responded to seasonal effects in a similar manner to natural algal populations in the stream.

A comprehensive study using artificial substrates and chlorophyll a measurement was later carried out by Flemer (1970), who assessed the influence of nutrient levels on primary production and showed a seasonal pattern of primary productivity and standing crop. The effect of nutrient levels on growth of algal mat communities has also been examined by Wilhm and Long (1969) in laboratory experiments which showed that biomass and chlorophyll levels increased fastest and reached highest levels under the highest nutrient conditions, Cooper and Wilhm (1970) examined the variation of periphyton production downstream from an effluent outfall and found that the productivity of periphyton decreased with distance from the outfall. Finally, Kehde and Wilhm (1972) considered grazing of invertebrates on periphyton growing on an artificial substrate, a subject which had received only token consideration before this. They showed that periphyton biomass was unaffected by low concentrations of grazers but that the level of chlorophyll a production was significantly increased by the activity of grazers.

The aim of the present study was to examine the growth rates and accumulation of periphyton standing crop in different parts of the Leeston drain and to relate these to the degree of organic enrichment found. Evaluation of this method as a measure of pollution was also undertaken.

9.2 Methods

As Wetzel (1964, 1965) has pointed out slow and partial colonisation by algae may occur on many artificial substrates. In an attempt to avoid this problem a standardised form of natural substrate was used in this study.

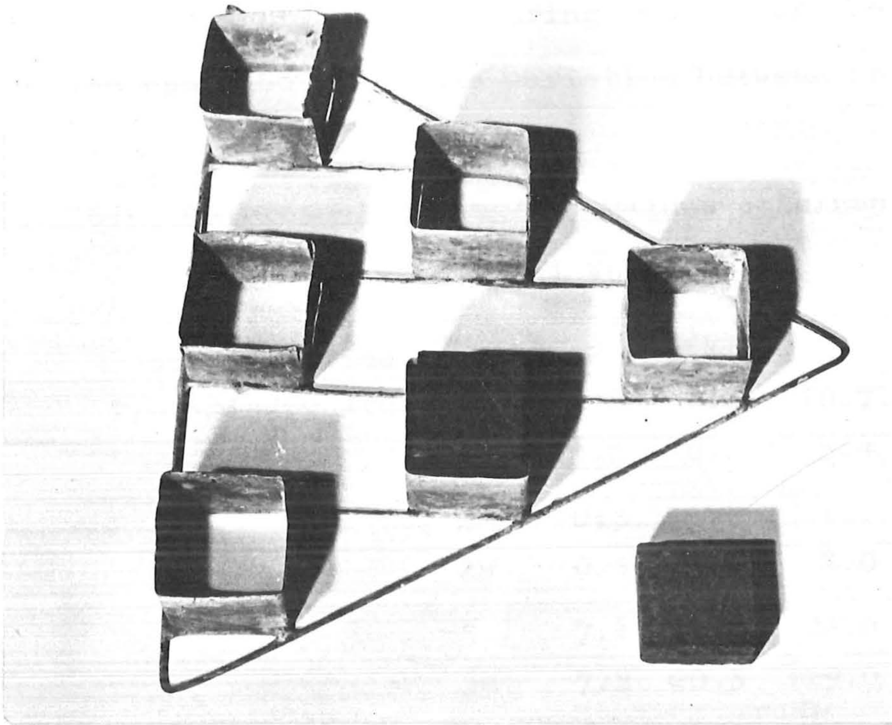
The natural substrate of the Leeston drain is a modified sedimentary rock known as greywacke. Boulders of this rock were cut with a diamond saw into small blocks which gave an exposed surface area of 320 mm^2 for algal attachment. Six blocks were placed in a triangular frame (Plate 13) which was buried in the substrate and the blocks were allowed to protrude 10 mm above the stream bed. This simulated the actual orientation of the substrate in the stream bed. Duplicate sets of holding frames and racks were placed at each station.

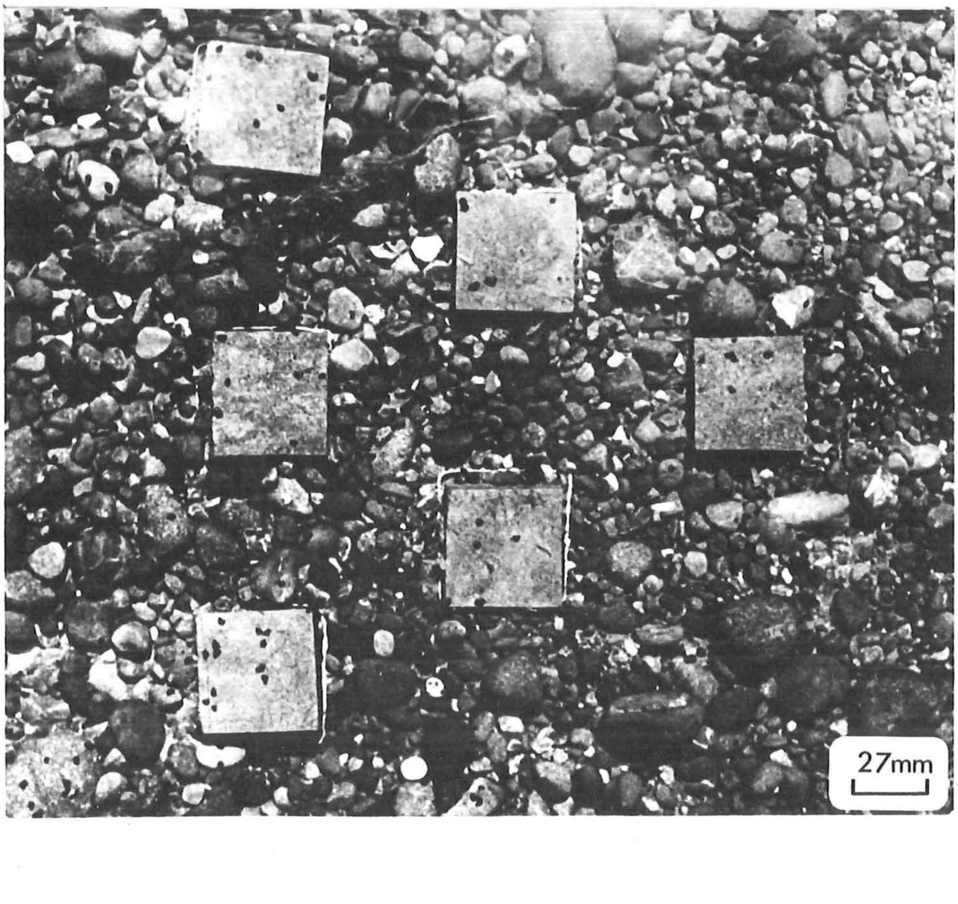
A pilot study showed that the artificial substrates had to remain in the stream for up to six weeks to allow the algal standing crop to reach the asymptote of the growth curve. Duplicate substrates were used in the pilot study and in the third experimental series. However, a shortage of substrates due to theft precluded duplicates being placed in series one and two.

Chlorophyll extraction method: Blocks were removed from the stream every 14 days placed in 125 ml of freshly redistilled 90% acetone and stored in a box to reduce the effect of sunlight. In the laboratory attached algae were macerated with a stainless steel spatula and replaced in the acetone to complete the extraction, which was carried out in the dark for 24 hrs at $4^{o}C$. The extracted solution was centrifuged and absorbancy of the supernatant fluid measured at 750, 665, 430 and 410 nm on a Pye Unicam Spectrophometer. Chlorophyll a and phaeophytin concentrations were calculated according to Moss (1967a,1967b). Species composition of the algae was not examined and the chlorophyll a level was taken as a general measure of actively respiring periphyton biomass.

In the preliminary study and series three chlorophyll values obtained from duplicate blocks showed some variation (Table 28).

PLATE 13: Cut greywacke blocks and block holder before positioning on the stream bed (top) and in position on the stream bed (bottom).




27mm

The major discrepancy between duplicates was caused by parts of the mat sloughning off and became noticeable in the later stage of the experiment. Scouring by silt of the algal mat could also contribute to this variation between replicates.

TABLE 28: Chlorophyll a (mg/m^2) values obtained from replicate artificial substrates.

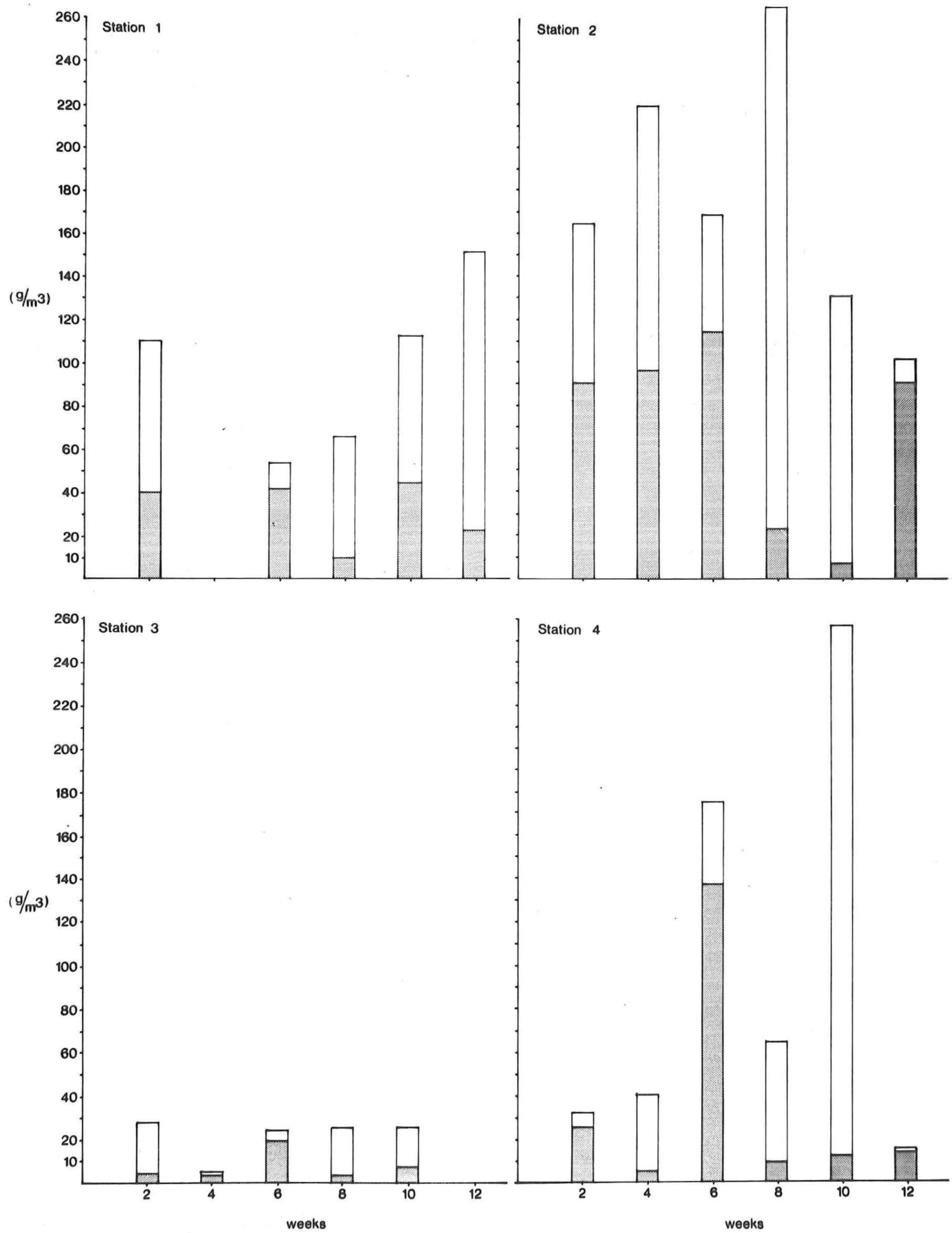
Sampling time (weeks)		2	4	6
Preliminary study	1	5.8	7.9	10.7
	1a	5.8	6.8	5.4
	2	0.3	1.4	1.1
	2a	0.5	0.9	2.0
	3	7.4	17.8	72.0
	3a	7.8	20.5	129.0
	4	4.2	1.0	2.2
	4a	4.8	0.6	1.8

Sampling time (weeks)		2	4	6	8	10	12
Final series	1	3.2	1.4	3.9	2.4	5.2	3.9
	1a	19.9	1.4	3.4	1.4	4.3	2.6
	2	7.3	0.9	7.0	8.7	2.9	3.9
	2a	10.7	1.7	1.4	9.9	15.0	7.9
	3	40.8	43.9	57.4	33.4	69.7	46.3
	3a	53.7	-	73.7	-	55.4	-
	4	6.4	0.20	10.7	3.7	9.9	3.4
	4a	8.5	0.5	6.4	8.7	8.6	1.0

9.3 Results

Series one: The sampling period extended from late winter to early spring (24/7/72 - 25/10/72) (Figure 24). At Stations 1 and 3 low levels of chlorophyll a (20 - 40 mg/m^2)

FIGURE 24: Accumulation of chlorophyll a and phaeophytin (mg/m^2) on artificial substrates at four locations in the Leeston drain between 24/7/72 and 25/10/72.
(non shaded = chlorophyll a, lightly shaded = phaeophytin).


Station 1
Station 2
Station 3
Station 4
(g/m3)
260
240
220
200
180
160
140
120
100
80
60
40
20
10
2
4
6
8
10
12
weeks

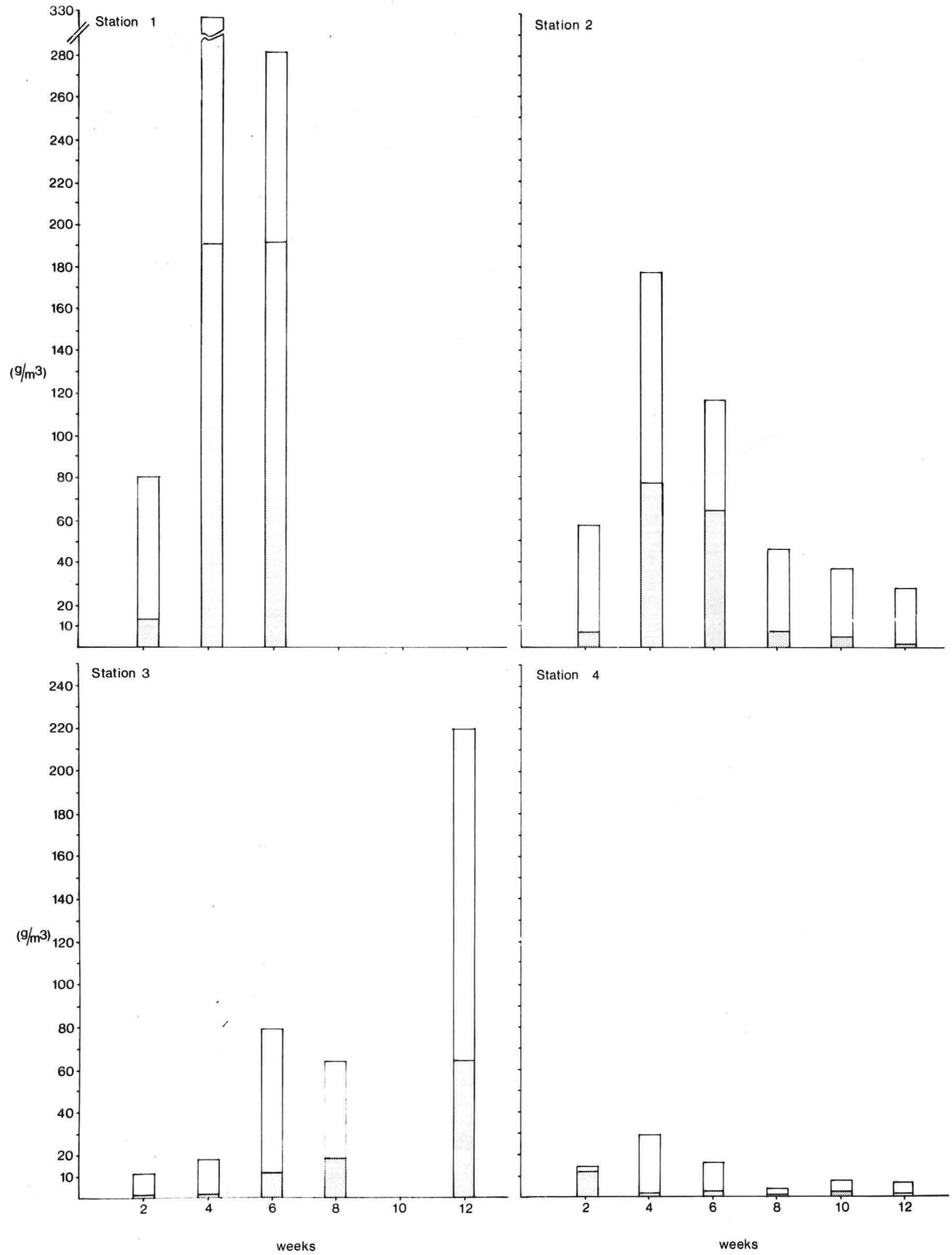
were found between the sixth and tenth week with levels at Station 3 being consistently lower than at Station 1. Station 2 had high chlorophyll a levels (117 mg/m^2) up to the sixth week after which the level dropped to 9 mg/m^2 by the tenth week. The last sample of this series showed a rapid accumulation of chlorophyll a with little phaeophytin present. Station 4 reflected the same pattern as Station 2 but did not reach as high a level in the late winter.

Phaeophytin values were variable but there was a general increase in the amount of phaeophytin on the substrate during the course of the trial. The variations in phaeophytin levels at Stations 2 and 4 corresponded to the period of senescence and subsequent sloughing off of the winter algal mat about the eighth week of the series. Most of the pigment present at this time was phaeophytin but by the twelfth week little phaeophytin was found. The low levels of phaeophytin found at Station 3 suggest there was little active growth at this station.

Series two: This series from late spring to early summer (25/10/72 - 15/1/73) (Figure 25). At Station 1 the chlorophyll a concentration increased rapidly to 190 mg/m^2 by week six. Theft of the blocks after this prevented further observations being made but algae on the surrounding shingle suggested that the algal standing crop remained high throughout the time of this experiment.

At Station 2 a rapid build up of chlorophyll occurred in the first four weeks (up to 78 mg/m^2) this was followed by a decline and an increase in the relative abundance of phaeophytin. Chlorophyll levels at Station 4 remained low

FIGURE 25: Accumulation of chlorophyll a and phaeophytin (mg/m^2) on artificial substrates at four locations in the Leeston drain between 25/10/72 and 15/1/73.
(non shaded = chlorophyll a, lightly shaded = phaeophytin).

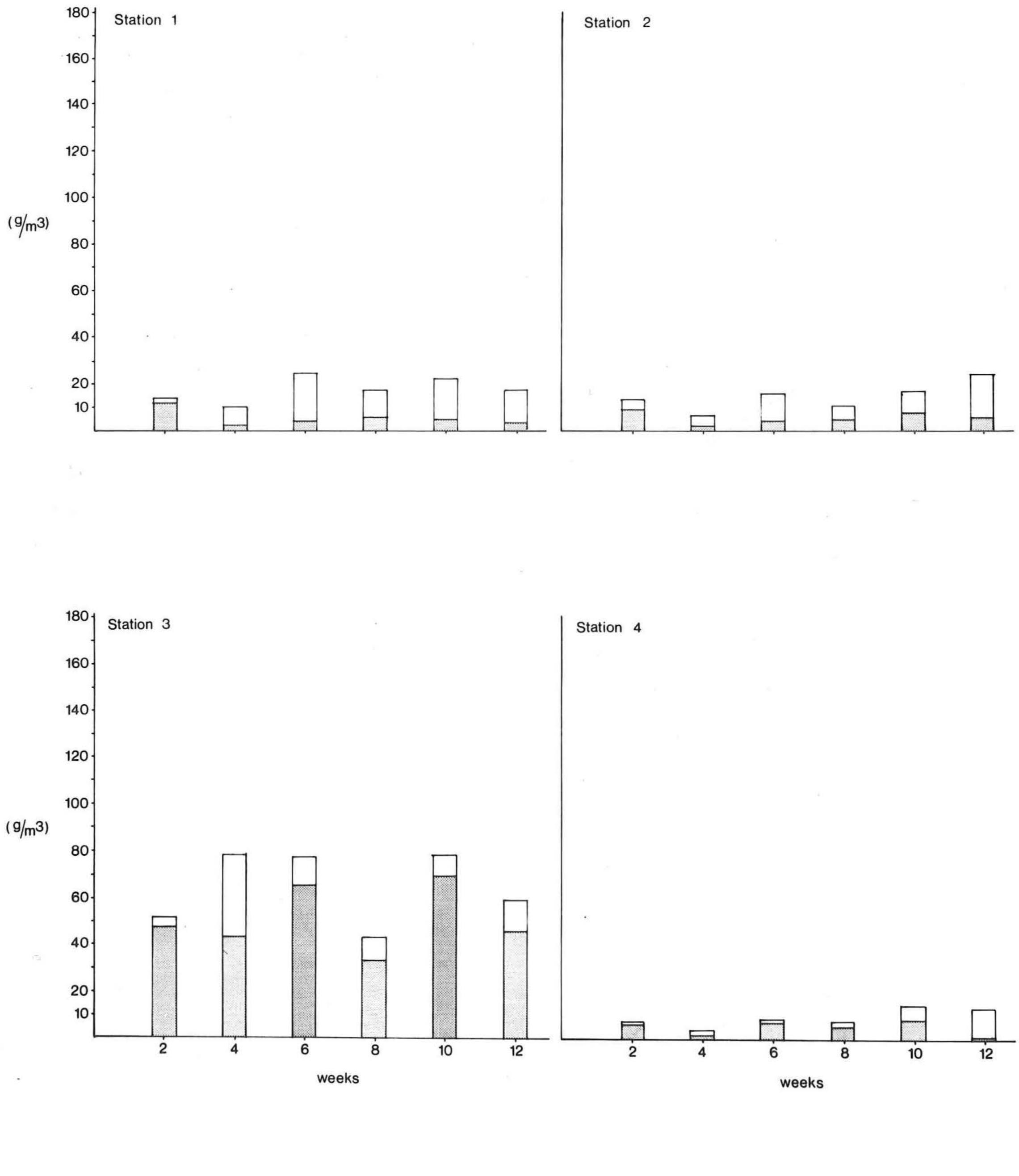

Station 1
Station 2
Station 3
Station 4
(g/m3)
(g/m3)
330
280
260
240
220
200
180
160
140
120
100
80
60
40
20
10
2
4
6
8
10
12
weeks
weeks

(1 - 12 mg/m^2) throughout the series, and phaeophytin levels were always higher. The low level of both chlorophyll and phaeophytin suggests that during this series little active growth was occurring at Stations 2 and 4. A gradual increase in chlorophyll a was found at Station 3 throughout this series and by the twelfth week it had reached 65 mg/m^2. There was always more phaeophytin than chlorophyll present at this station.

Series three: The length of this series was from summer to early autumn (15/1/73 - 8/4/73) (Figure 26) and was characterised by a reduction in the total pigment levels at Stations 1, 2 and 4 compared to the first two series and an increase at Station 3. At Stations 1, 2, and 4 chlorophyll levels were low throughout (1.0 - 10 mg/m^2), but a rapid initial increase in chlorophyll to 47 mg/m^2 occurred at Station 3, and this level was more or less maintained for the length of the series. Amounts of phaeophytin did not exceed the chlorophyll levels at this station indicating that the algae were actively growing during this period.

Effect of invertebrate grazers on the algal standing crop: The influence of invertebrate grazers (gastropod molluscs) on algal production on artificial substrates has been examined by Kedhe and Wilhm (1972) who demonstrated that at a density of 0.012 snails/cm^2 there was a slight reduction in algal standing crop and a significant increase in chlorophyll a levels compared with the situation where snails were absent. They postulated that the activity of snails released bound nutrients and stimulated the growth of algae consequently increasing chlorophyll a levels. In my experiments the

FIGURE 26: Accumulation of chlorophyll a and phaeophytin (mg/m^2) on artificial substrates at four locations in the Leeston drain between 15/1/73 and 8/4/73. (non shaded = chlorophyll a, lightly shaded = phaeophytin).


Station 1
Station 2
Station 3
Station 4
(g/m3)
180
160
140
120
100
80
60
40
20
10
2
4
6
8
10
12
weeks

chlorophyll a level was used as the indicator of algal biomass, and the presence of grazing invertebrates would no doubt have influenced the values obtained to some extent. In particular, the gastropod, Potamopyrgus antipodarum was regularly seen on the experimental blocks (Plate 13), and their numbers were determined on three occasions (Table 29).

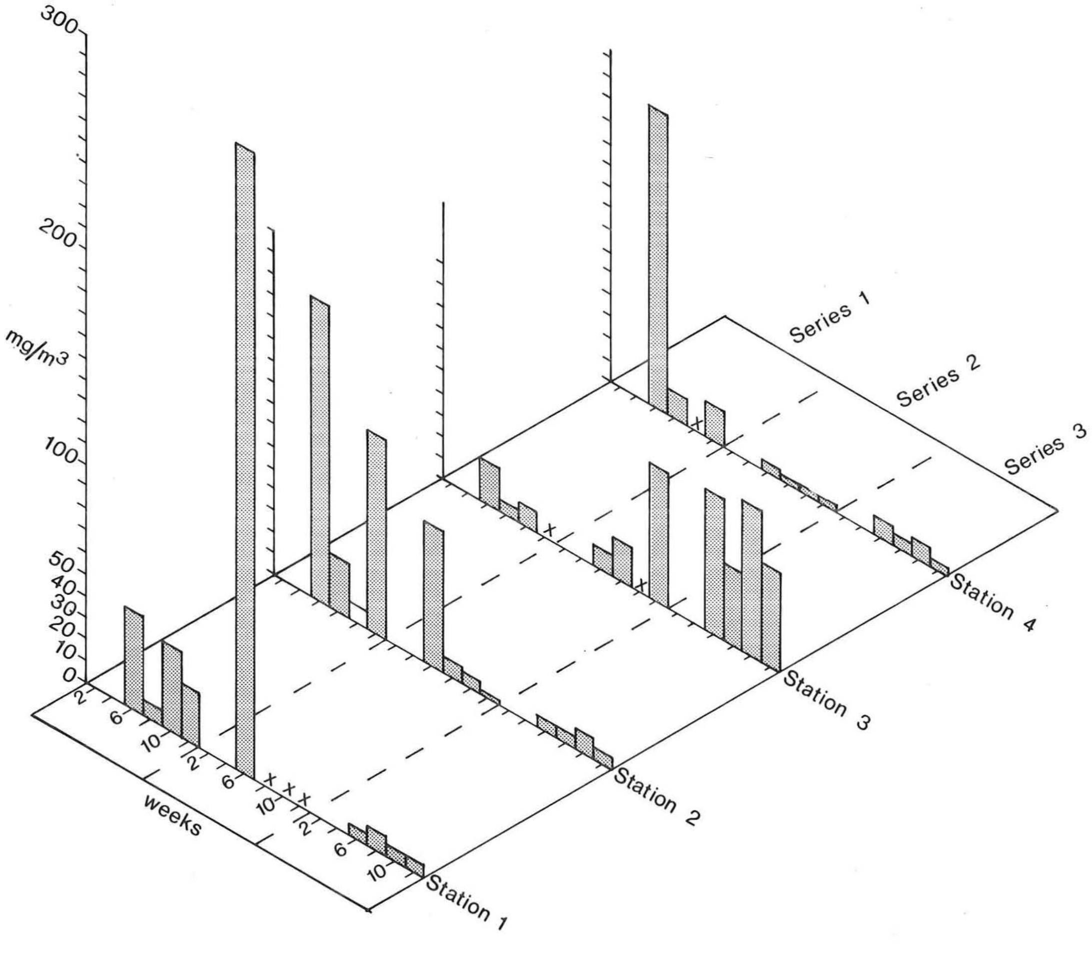
Snail densities were up to 100 times greater than those used by Kedhe and Wilhm (1972) in their experiments, and it is therefore possible that these snails could have had a greater effect on chlorophyll levels than in their study.

TABLE 29: Mean numbers of Potamopyrgus antipodarum seen on artificial substrates on three occasions. (n = 2)

	Stations			
Sampling period	1	2	3	4
6/3/72	0.34	0.09	0.37	0.09
20/3/72	0.94	0.31	1.09	0.09
3/4/72	1.15	0.31	1.15	0.31

Seasonal fluctuations in algal standing crop: During the course of the third series it became apparent that the maximum standing crop levels were influenced by some factor other than different nutrient levels in the stream. This resulted in alterations in the amount of chlorophyll present and in the general appearance of the algae. On combining the data representing the asymptotic phase of each experimental series (i.e. excluding values obtained in the initial growth phase - first four weeks) seasonal trends in chlorophyll levels of established algal mats could be discerned (Figure 27).

FIGURE 27: Seasonal fluctuations in maximum chlorophyll a levels at four stations in the Leeston drain between 24/7/72 and 8/4/73.
(X = lost samples).



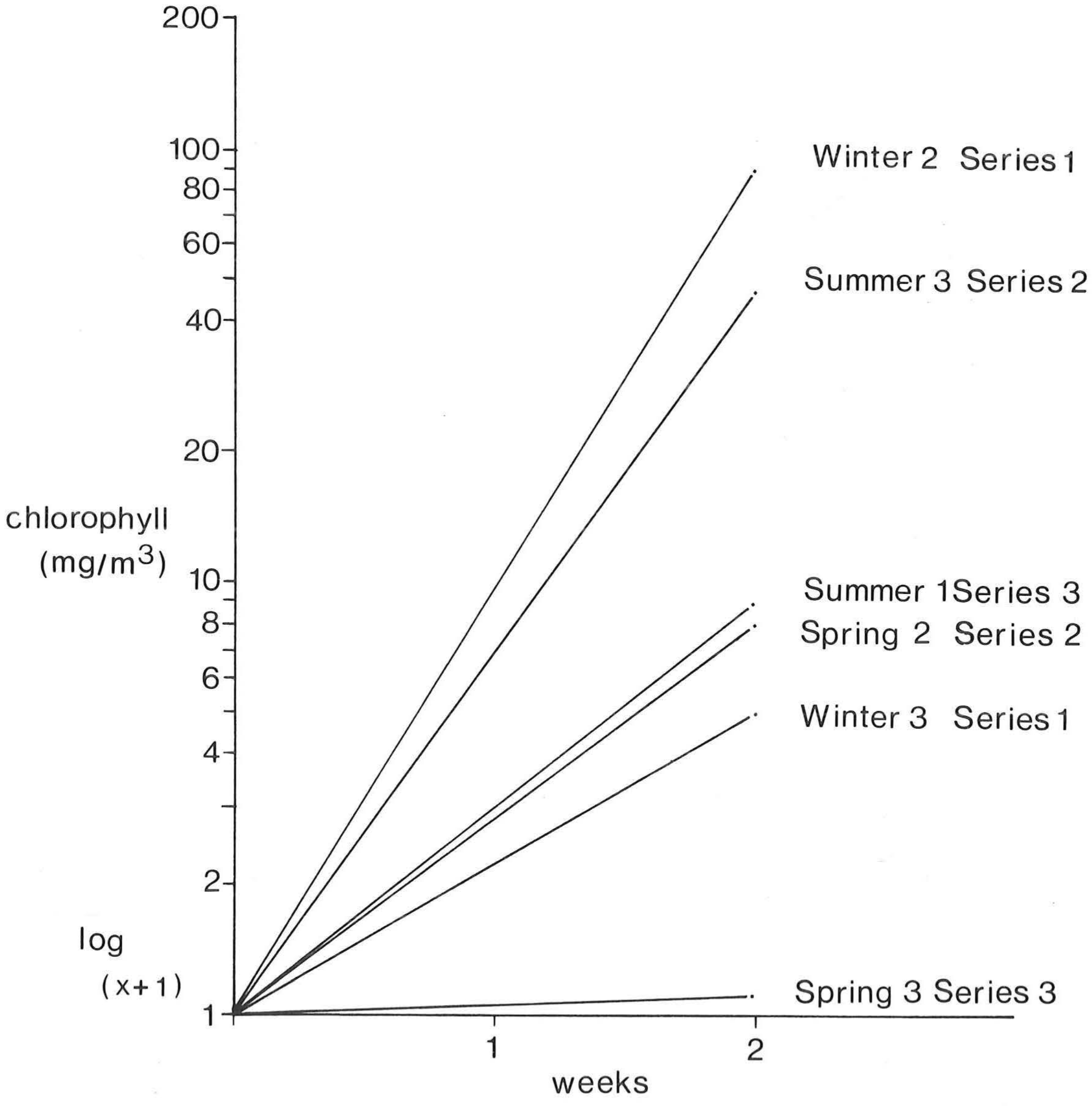
300
200
100
50
40
30
20
10
0
mg/m3
2
6
10
2
6
10
2
6
10
weeks
Series 1
Series 2
Series 3
Station 1
Station 2
Station 3
Station 4

At Station 1 there was a build up of algal biomass during late spring and summer followed by a decline in late summer - early autumn. Station 3 had a slower rate of accumulation and maximal standing crops occurred in late summer and autumn. A different pattern was found at Stations 2 and 4 where there was a build up of chlorophyll a in winter when mats of filamentous algae developed. These algae were completely sloughed off in spring and replaced by encrusting forms, primarily diatoms, having a much lower chlorophyll content.

Analysis of growth rates: Kevern et al. (1966) showed that the slope of the exponential growth phase provided a close approximation to the production rate of periphyton. Subsequently, Cooper and Wilhm (1970) compared the exponential growth phase of algae at different stations in a polluted stream in Oklahoma and concluded that the slope of the growth phase curve was related to the distance downstream from a pollution (nutrient) outfall, the station nearest to the outfall having the highest growth rate.

In the present study growth rates were compared over the first 14 days in each series. At Stations 2 and 3 these were variable (Figure 28) and the differences found appeared to be related primarily to the changes in species composition occurring at different times of the year. In fact, similar growth rates were found at the non-enriched Station 2 and the enriched Station 3 at different times of the year (Figure 28). No relationship between growth rate and proximity to nutrient sources, such as that observed by Cooper and Wilhm (1970) was found.

FIGURE 28: Rate of chlorophyll a accumulation in the first 14 days of each series at the four stations in the Leeston drain.


200
100
80
60
40
20
10
8
6
4
2
1
chlorophyll
(mg/m3)
log
(x+1)
1
2
weeks
Winter 2 Series 1
Summer 3 Series 2
Summer 1 Series 3
Spring 2 Series 2
Winter 3 Series 1
Spring 3 Series 3

<u>Factors influencing algal growth rates</u>: It was not the aim of my work to examine in detail seasonal differences in algal growth but some discussion of this question is necessary if studies of this type are to be useful in assessing degrees of enrichment or pollution in running water. Water temperature was measured during the experiment and showed a normal seasonal rise to a summer maximum (Figure 3). Although the temperatures at different stations were similar, Station 3 had both the highest and lowest recorded temperatures (25^{o}C and 7^{o}C).

The pH did not vary greatly between stations or at different times. Detectable differences in phosphate and nitrate levels were found between stations, but, during the course of the experiments the relative levels did not vary much. Station 3 had the highest mean phosphate and nitrate levels (0.055 g/m^3 and 3.3 g/m^3 respectively) and Station 2 the lowest levels (mean phosphate, 0.013 g/m^3; nitrate, 1.36 g/m^3). At different times of the year, each of these stations had the highest chlorophyll a levels in the stream, so it appears that at all stations there were sufficient nitrients to support continuous algal growth throughout the year.

No scouring of the substrate occurred in the stream but some siltation occurred, being greatest at Stations 1 and 2 because of precipitation of suspended matter from the water. This siltation did not appear to influence growth rates because maximum and minimum algal growth occurred both in high and low siltation sites depending on the season. Some workers, Cooper and Wilhm (1970), Grzenda and Brehmer (1960), and Kevern et al. (1966), attempted to avoid siltation occurring by suspending artificial substrates vertically in the water column. This practice may give misleading results however, as the algae attached may not be true epilithic assemblages (Dumont 1969; Wetzel 1965).

Light and temperature are the most obvious factors controlling algal growth and their effects are very difficult to separate as they tend to vary simultaneously. The amount of light reaching the stream bed is dependent primarily on the angle of incidence of the sun as well as any shading from obstructions such as fences and trees on the banks of the stream.

Station 3 was heavily shaded in the winter and there was little algal activity during this time, however, Stations 2 and 4 were not shaded and algal activity in the winter was high. In summer there was little shading at Station 3 and algae bloomed, but at Stations 2 and 4 where the stream was very exposed there was little algal growth. Although intensity of light could affect the growth of algae at any one station it does not account for the different growth patterns found along the length of the stream. It is possible that these differences in algal growth are due to different responses to light by separate algal assemblages, occurring at different stations.

The summer blooms found at Station 3 are most likely produced by algal species as a result of nutrient enrichment and have replaced the species originally present. This type of replacement phenomenon has been well documented by Butcher (1932, 1940, 1947). The replacement algae probably have a higher light threshold and optimum light intensity than the original colonisers as growth was found to be minimal in winter but considerable in the summer. The fall of algal activity in early summer at Station 1 could possibly be the result of over shading of the stream bed by adjacent willow trees. Support for this idea comes from observations made by Minckley (1963) in a stream that ran through unmodified deciduous forest, where the wax and wane of algal growth was tied to increasing spring light levels and the opening of the leaves in the overhead canopy reduced light levels and consequently algal growth.

9.4 Conclusion

In the absence of taxonomic studies and light measurements in the present study, these observations can not be tested but it appears likely that the seasonal changes in algal growth were controlled by some factor, most probably light, operating on different algal assemblages in different parts of the stream. The similation model by McIntire (1973) showed that light penetration, grazing of algal mats, and scouring by silt during rainy seasons limit algal growth : nutrient levels were not a limiting factor. This result largely substantiates the explanations put forward by the author.

Evaluation of artificial substrates as monitors of stream enrichment: The results of my study have shown that measurements of algal production on artificial substrates have serious limitations as a pollution assessment method. Seasonal changes in particular can alter the levels of chlorophyll produced during the course of the experiment to a greater extent than can nutrient levels alone. Also, differences in taxonomic composition of the algal communities are likely to occur where different nutrient conditions occur, and these can have important affects on production levels attained. Physical parameters of light reaching the substrate during the course of an experiment may also have important effects on algal growth rates.

The method could still be usefully employed in pollution studies if:-

1 The substrates are placed in position for no more than five weeks to avoid gross seasonal effects.

2 Replicate substrates are collected at short intervals of time e.g. 3, 6, 9, 12, 15, 18 etc. days and analysed for growth rates only.

3 Homogeneity and synchrony of algal growth is determined prior to and during experimentation.

4 The effects of different light regimes are considered.

SECTION C

CONCLUSION

10 SYNTHESIS AND RECOMMENDATION

10.1 Synthesis

1. The Leeston drain has two major sources of pollution, one from the Leeston township and the other from a dairy shed outlet. In between these polluted areas clean stream conditions prevail. The effects of pollution on the benthic fauna in the drain is more pronounced at and below the Leeston township where only tolerant faunal elements persist. Below the dairy outlet pollution is less severe and although there is a reduction in species diversity some clean water animals persist.

2. An attempt has been made to show the extent of the alterations to the stream environment caused by pollution and to indicate the changes in the faunal community structure as a result of these alterations.

3. Field experiments have examined the interactions between environmental conditions and the biology of two species of oligochaete which are tolerant of pollution.

4. By using artificial substrates placed in the drain it has been shown that although the presence of high nutrient water can increase primary production, physical factors (e.g. light, temperature) common to both clean and enriched water limit production to a greater extent than nutrients.

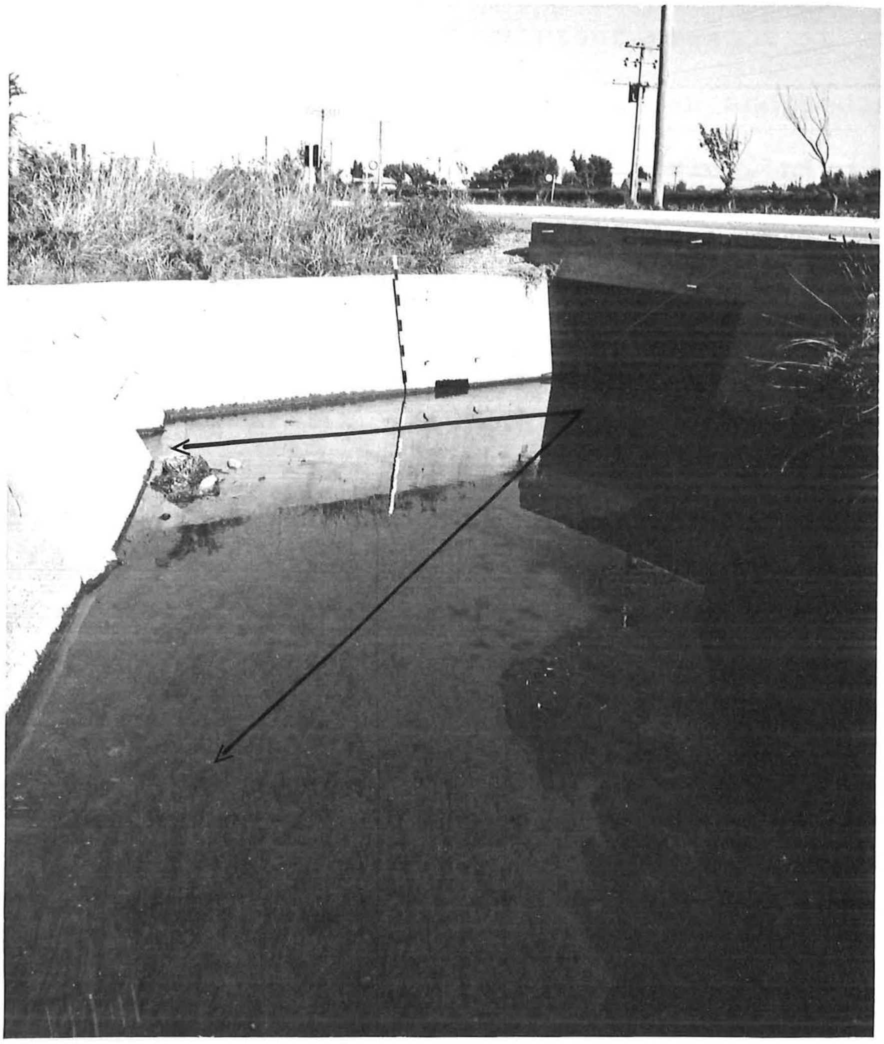
5. With the diversion of the effluent away from the Leeston drain in future years, it is felt that presently polluted areas of the drain will recover. This recovery will be assisted by the regular removal of nutrients by weed cleaning, and the fauna from upstream areas will assist in recolonisation of the area as it improves. The effect of sewerage effluent from the treatment ponds, at present under construction will probably be noticeable immediately downstream from the pond outlet.

6. It is predicted that a layer of fine organic sediment will develop and faunal diversity will consequently decrease. As discharge of this effluent is to be intermittant it is doubtful if a large area of the drain will become polluted. If for any reason discharge of effluent becomes continuous there could be further changes in the faunal composition. Pollution influences could become extensive in the drain.

7. The high macrophyte production that is associated with the present level of nutrients in the drain is expected to develop below sewerage treatment outlets and may help to prevent excessive amounts of nutrients finding their way into the already enriched Lake Ellesmere.

PLATE 14: Water from Leeston drain dividing into drains 53 (bottom) and 58 (top).

(photo: J.W. Marshall).



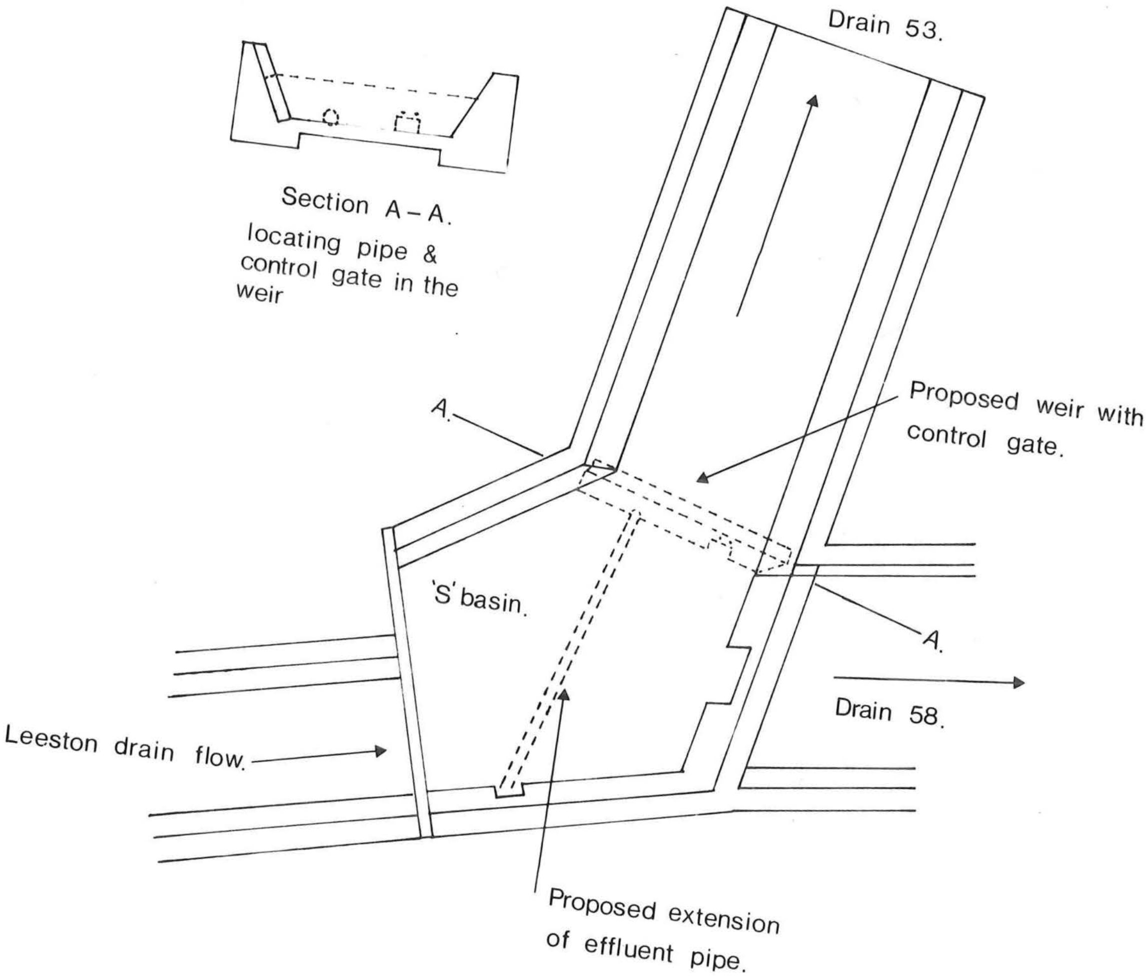
10.2 Recommendations

1. The Ellesmere County Council has permission to discharge secondary treated sewerage into the Leeston drain during the autumn and winter months. As only low levels of primary production occur during these periods it is probable that high levels of nutrient present in the effluent will be taken up by flocculation and sedimentation rather than by plants. During spring, high flows may flush this material into Lake Ellesmere before plants can utilise it. In view of this I am proposing that some form of stream management be practiced using aquatic plant growth and sedimentation to strip the excess nutrients from the water. This activity could be carried out in the 3 km section downstream from the proposed outlet (which is 50 m downstream from Station 3), as here there are two alternative channels down which water can flow away (Plate 14). The Tramway Road drain (drain 53) has been designated for sewerage flow, and the stream (drain 58) that runs through the farmland is restricted to clean water only. I propose that some form of control should be set up in the area of the proposed outlet to control flow rate and flow direction as follows:-

   i During spring and summer a small amount of water should flow down drain 53 and the majority down drain 58. This would supply sufficient water for maximum aquatic plant growth down drain 53.

   ii During winter, any sewerage discharge should be directed into Tramway Road drain and normal stream water be allowed into the farmland stream.

FIGURE 29: Leeston drain divide showing position of proposed modifications. (Traced from Ellesmere County plan 298).



Scale ;

25·4 mm to 1270 mm
(1 inch to 50 inches)

iii In spring any increased discharge other than floods from the upstream catchment should be directed into the farmland stream to reduce the problem of flushing high nutrient sediments from the Tramway Drain before plants can utilise it.

2. Annual weed cleaning activity in this section should continue to be carried out in late summer. This would ensure maximum assimilation by plants of nutrients laid down in the preceding autumn and winter and at the same time allow some regrowth of weed to assist in sediment trapping during the autumn and winter. During cleaning, attempts should be made to remove the top 30 mm of sediment along with the weeds. The use of a clam grab rather than a scraper blade is suggested and the material should be trucked away and dumped. Mechanical cleaning of the section around Leeston is also recommended to remove the accumulated organic sediment.

3. In line with the proposal outlined it is felt that modifications to existing Leeston drains 53-58 divide (Ellesmere county plan 298) should be carried out:-

i The 150 mm (6 inch) diameter effluent outlet pipe should extend across the "S" basin (Figure 29) to the throat of drain 53. The pipe should be placed as near flush with the concrete floor of the channel so that the flow of effluent will be as smooth as possible. This will reduce the problem of foaming as the effluent is discharged.

ii Flush with the end of this pipe a 685 mm (2 ft 3 inch) weir should be constructed across the flood channel to control all but extremely high discharge. In accordance with this proposal most of the drain water would go down drain 58 but a small control gate set in this weir would allow sufficient water to pass down drain 53 and maintain weed growth. This discharge need not be continuous.

4. If this management programme is implemented there should be:-

i Minimal loss of nutrients by re-suspension during periods of high discharge.

ii Maximal uptake of nutrients by plants.

iii Effective removal of nutrients from the drain system as plant tissue and enriched sediment.

iv Limited nutrient input into Lake Ellesmere.

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APPENDIX I

An illustrated key to the more common freshwater Oligochaeta in New Zealand : based on R.O. Brinkhurst's (1971) Australasian key.

Introduction

It is difficult in New Zealand to obtain positive identification of even the most common species of oligochaetes. Because of this the author felt that photographs of the diagnostic features of the more common species would bridge the gap between illustrations used in written keys and what a novice observes down a microscope.

The collections of Dr V.M. Stout which had been identified by Dr R.O. Brinkhurst, and a small collection named by Dr M. Ladle and presented to the author provided positively identified species. Photomicrographs were taken of these species and incorporated in the body of Brinkhurst's (1971) key. It is the author's intention that the photographs should assist in the interpretation of the written key and not be regarded as a complete key in themselves.

Once confidence in the identification of the more common species has been obtained the sometimes subtle differences of the less common species will become apparent.

Because of the importance of oligochaetes in the benthic ecosystem it is imperative that all workers in freshwater benthos become familiar with this group. If this publication assists the beginner with initial identification and allows them to progress to the more comprehensive traditional keys it will have served its purpose well.

Notes on Methods

NARCOTISING - bubble carbon dioxide into water containing worms.

PRESERVATIVE - 10% formalin
or 70% alcohol (caution,unless the solution is isotonic there is a tendency for the worms to explode.

MOUNTING AND CLEARING AGENTS - Lactophenol polyvinyl aldehyde (LPVA). The addition of lignin pink to LPVA facilitates location of cleared worms on the slide.

Key

1. KEYS TO FAMILIES

1. Prostomium ciliated. Internal septation incomplete. Hair chaetae in all chaetal bundles. Minute worms (up to 10 mm, normally much smaller - c. 1 mm).
Aeolosomatidae (?Archiannelida)
(Only two species to date, _A_. _niveum_, _A_. _hemprichi_)

- Prostomium naked. Septation more or less complete. Hair chaetae in dorsal bundles or absent. Almost always larger than 10 mm. 2

2. Chaetae two per bundle............................... 3
- Chaetae more than two per bundle.................... 4

3. Chaetae simple pointed Family Haplotaxidae - Key 2
- Chaetae bifid with upper tooth small to indistinct
Family Lumbriculidae - Key 3

4. Dorsal chaetae start on III, hair chaetae plus short chaetae not emerging from chaetal sacs, or on posterior segments only in parasitic forms. Ventral chaetae paired, often one bifid and one simple pointed, often differ in thickness.
Family Phreodrilidae - Key 4

- Dorsal bundles from II or from V, VI or posterior bundles or absent. Ventral chaetae numerous, almost always bifid 5

5. Usually less than 2 cm, long, delicate transparent worms, sometimes with eyes and/or gills, or proboscis developed on prostomium. Pectinate chaetae rare in dorsal bundles. May burrow in mud, or swim, or crawl over weed. Asexual reproduction forming chains.
Family Naididae - Key 5

- Usually more than 2 cm, long, red worms that coil readily, without eyes, proboscis, or gills (except _B. sowerbyi_-qv). Pectinate chaetae often present in dorsal bundles where hair chaetae occur. Always burrow in sediment, head down. Asexual reproduction rare, not forming chains.
Family Tubificidae - Key 6

2. KEY TO FAMILY HAPLOTAXIDAE

1. Ventral chaetae large, single; dorsal chaetae small
H. heterogyne

- Chaetae paired and all of a similar size............ 2

2. Two pairs of ovaries _H. smithii_

- One pair of ovaries.................................. 3

3. Both pairs of male pores on XII, close together
H. violaceus

- Male pores separate in XI and XII
H. africanus

3. KEY TO FAMILY LUMBRICULIDAE

1. Chaetae bifid, with upper tooth much finer and reduced. Sexually mature forms rare, regenerating segments common.

   <u>Lumbriculus</u> <u>variegatus</u> (Figures 1 & 2)

- Chaetae bifid and stout, with upper tooth reduced or absent. Sexual forms frequent with paired elongate (300 µm) pene on 10th segment.

   <u>Stylodrilus</u> <u>heringianus</u> (Figures 3 & 4)

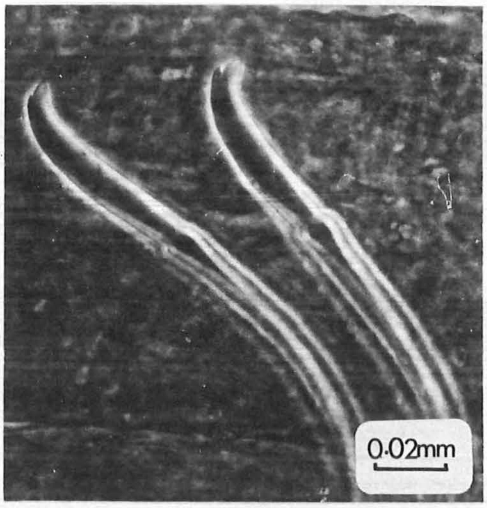

FIGURE 1

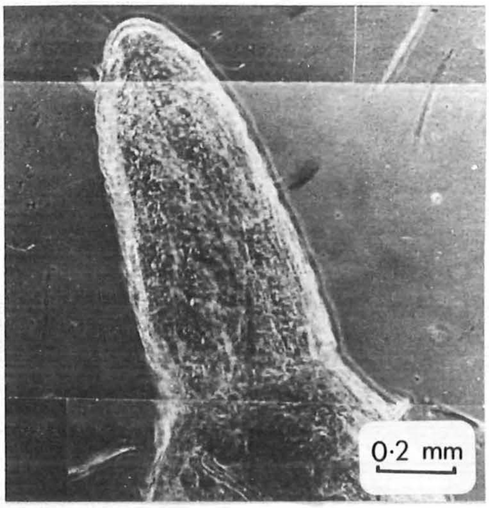

FIGURE 2

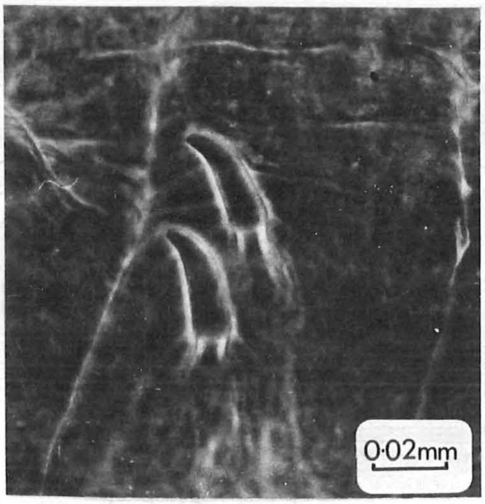

FIGURE 3

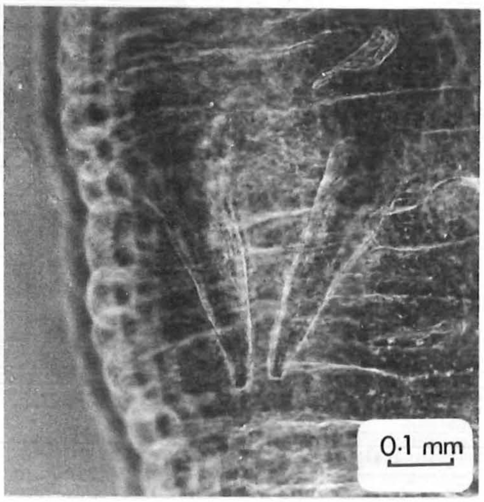

FIGURE 4

4. KEY TO PHREODRILIDAE

1. Living on crayfish Astacopsis.................... 2
- Free living... 3

2. Dorsal chaetae from XXXI-XLIII — *P. goddardi*
- Dorsal chaetae from IV — *P. fusiformis*

3. Spermathecae absent — *P. notabilis*
- Spermathecae present in mature specimens........... 4

4. Spermathecal pores dorso/lateral.................. 5
- Spermathecal pores ventro/lateral................. 7

5. Inner duct of pseudopenis coiled once or twice within muscular sac — *P. beddardi*
- Inner duct of pseudopenis coiled many times within muscular sac.............................. 6

6. Ventral chaetal bundles with one bifid and one simple pointed chaeta — *P. mauienensis* (Figure 5)

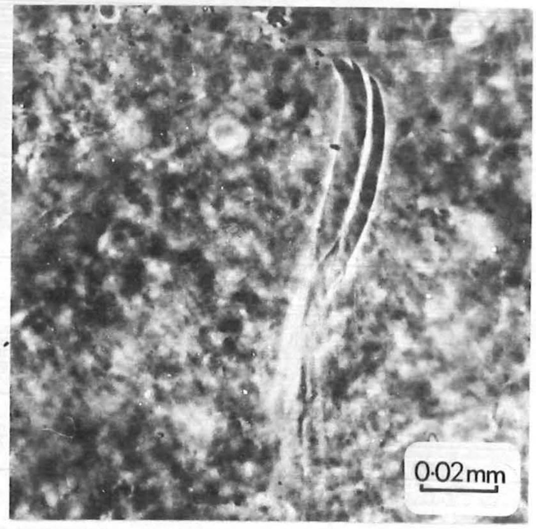

FIGURE 5

- Ventral chaetal bundles with chaetae dissimilar in form but both simple pointed — *P. subterraneus*

7. Spermathecal chaetae unmodified in mature specimens — *P. campbellianus*

- Spermathecal chaetae modified in mature specimens...... 8

8. Spermathecal chaetae paired. Rudimentary vestibulae on spermathecal pores — P. lacustris
- Spermathecal chaetae single (?). Large muscular vestibulae on spermathecal pores — P. litoralis

5. KEY TO NAIDIDAE

1. Dorsal chaetae absent — Chaetogaster spp.
- Dorsal chaetae present.................................. 2

2. Dorsal chaetae beginning in II (Figure 6) Pristina - 3
- Dorsal chaetae beginning in IV, V, VI (Figure 7)...... 6

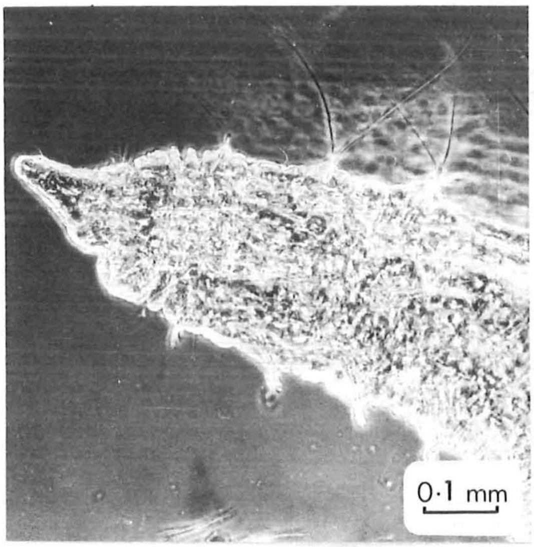

FIGURE 6

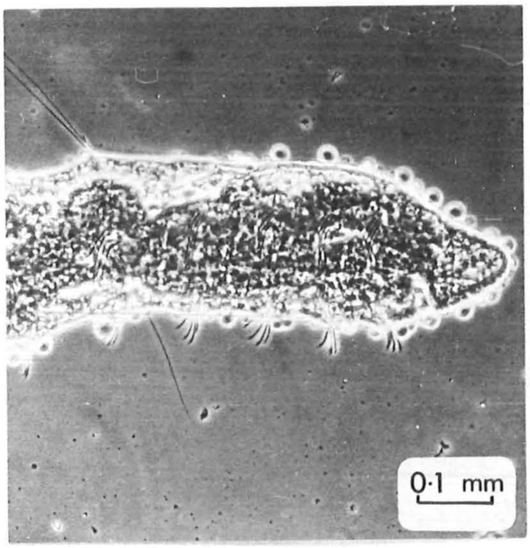

FIGURE 7

3. Proboscis absent. Needles bifid with long parallel teeth — P. idrensis
- Proboscis present.................................. 4

4. Hair chaetae of III longer than the rest — P. longiseta
- Hair chaetae of III similar to other hair chaetae..... 5

5. Needle chaetae simple pointed. No giant ventral chaetae — P. proboscidea
- Needle chaetae finely bifid. Enlarged giant chaetae often present in IV, V, or VI or some of these. — P. aequiseta

6. Gills present.................................... 7
- Gills absent..................................... 14

7. Gills ciliated digitiform processes on nearly all segments from VI on Branchiodrilus hortensis
- Gills bunched around anus Dero spp....... 8

8. Branchial fossa with palps Dero (Aulophorus) 9
- Branchial fossa without palps Dero (Dero).... 10

9. Dorsal chaetae begin in V, needles bifid
D. (A.) furcatus
- Dorsal chaetae begin in VI, needles palmate
D. (A.) flabelliger

10. Dorsal chaetae from IV. Two divergent processes on branchial fossa. (5 pairs of gills)
D. (D.) dorsalis
Dorsal chaetae from VI. No divergent processes on branchial fossa.................................... 11

11. Needles pectinate.................................. 12
Needles bifid...................................... 13

12. Needles with three equal teeth D. (D.) pectinata
Needles with lateral teeth and a series of fine intermediate teeth D. (D.) asiatica

13. Branchial fossa prolonged posteriorly D. (D.) nivea
Branchial fossa not prolonged D. (D.) digitata

14. Hair chaetae of VI elongate. Body wall encrusted with foreign matter Slavina appendiculata
(Figure 8).

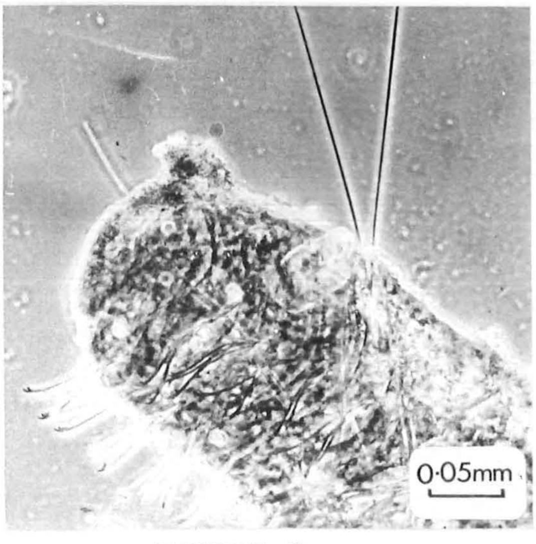

FIGURE 8

- No elongate hair chaetae. Body wall usually naked.. 15

15. Needles with fine teeth, short and equal or long parallel and equal   Nais   16

- Needles large, pectinate, or with teeth of obviously unequal thickness   Allonais   17

16. Needle teeth long, parallel, fine   N. elinguis (Figure 9)

- Needle teeth short, diverging   Nais sp. (probably N. variabilis and/or N. communis) (Figure 10).

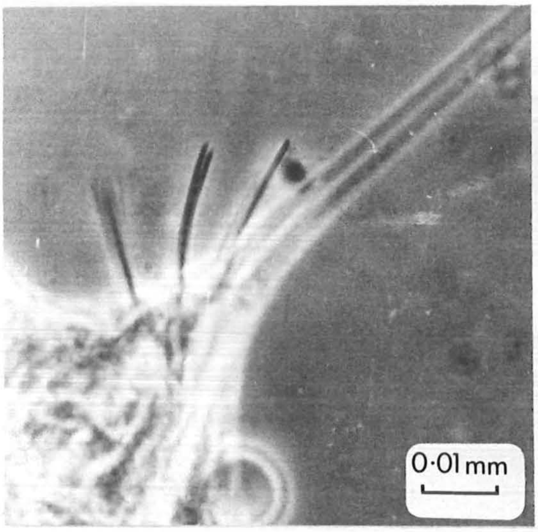

FIGURE 9

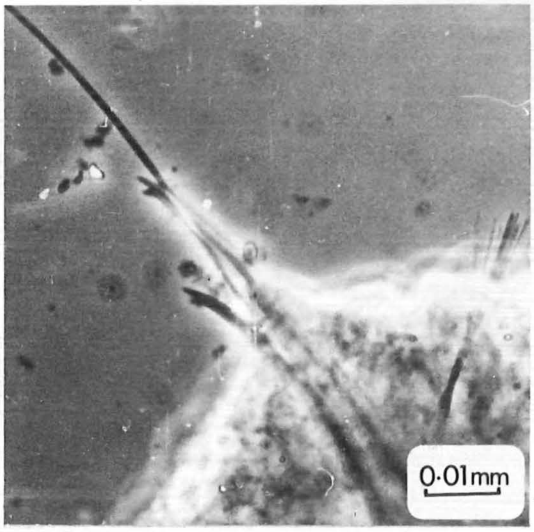

FIGURE 10

17. Needle teeth equally long or upper longer than lower, 1-5 intermediate teeth   A. pectinata

- Needle teeth, unequal, upper teeth shorter than lower... 18

18. Upper tooth of needle rudimentary, much thinner than lower, sometimes bifid   A. paraguayensis

- Upper tooth of needle distinct, 1-4 fine intermediate teeth present, or upper tooth appearing replicate   A. inaequalis

6. KEY TO TUBIFICIDAE

1. Gills present as mid dorsal and mid ventral filaments on posterior of body. Possibly found in hothouse lily ponds <u>Branchiura</u> <u>sowerbyi</u> (Figure 11)

- Gills absent.. 2

2. Chaetae all simple pointed <u>Telmatodrilus</u> <u>multiprostatus</u> (Figure 12)

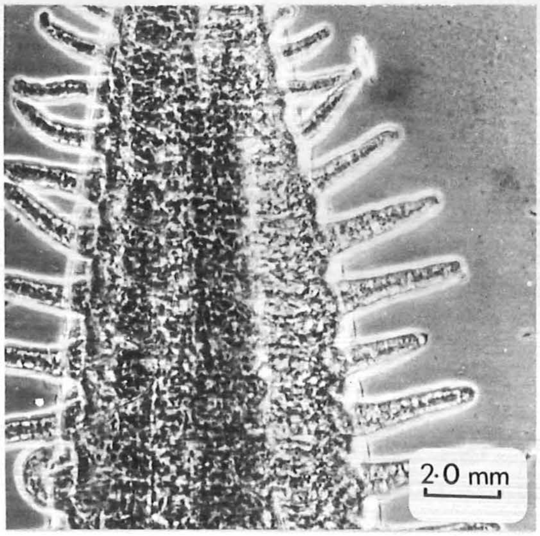

FIGURE 11

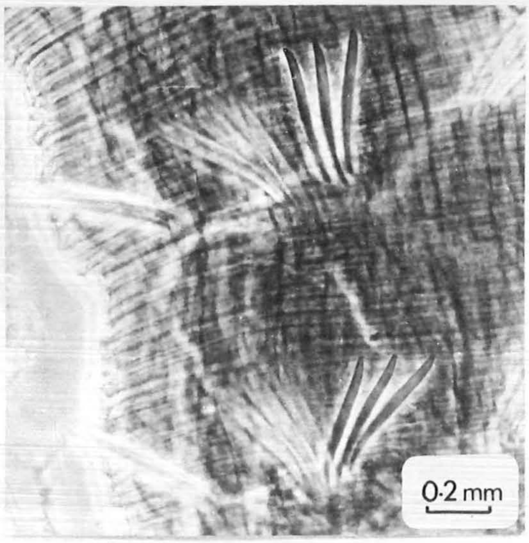

FIGURE 12

- Most chaetae bifid or pectinate..................... 3

3. Hair chaetae present................................. 4

- Hair chaetae absent.................................. 12

4. Hair chaetae very fine, spirally twisted (marine) <u>Monopylephorus</u> <u>irroratus</u>

- Hair chaetae stout, not twisted..................... 5

5. All chaetae relatively fine and numerous. Ventral chaetae and anterior dorsal chaetae (apart from hairs) bifid with upper tooth thinner and shorter than lower, upper tooth duplicate in some dorsal chaetae <u>Aulodrilus</u> - 6

- All chaetae relatively thick and not so numerous. Dorsal chaetae clearly pectinate with lateral teeth broad and intermediate teeth usually finer, ventral chaetae mostly bifid, mostly with upper tooth as or longer than lower (Figure 13)................... 7

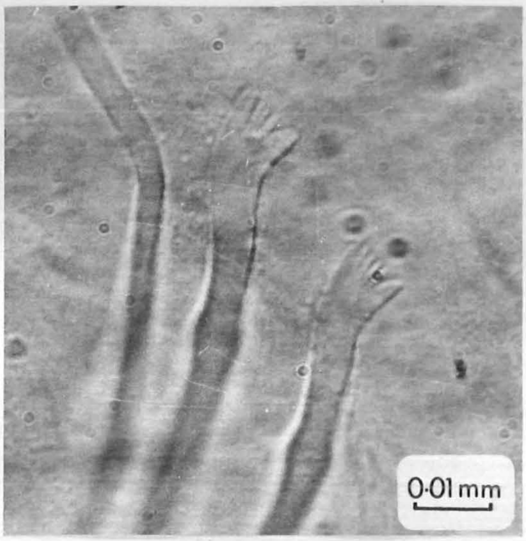

FIGURE 13

6. Dorsal chaetae from VI or so, oar shaped <u>A. pigueti</u>

- Dorsal chaetae all of one form, bifid with upper tooth shorter and thinner than lower <u>A. pluriseta</u> (Figure 14)

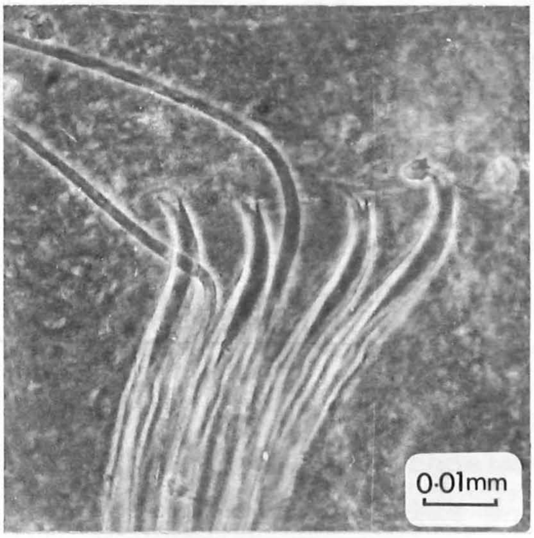

FIGURE 14

7. No modified genital chaetae in mature specimens <u>Tubifex tubifex</u>

- Modified genital chaetae present in mature specimens.. 8

8. Penial chaetae present on XI. Coelomocytes present Rhyacodrilus 9

\- Spermathecal chaetae present on X (unless genital region displaced forward by regeneration of head end).
Coelomocytes absent.................................. 10

9. Prostate glands absent R. simplex

\- Prostate glands present R. coccineus

10. Spermathecal chaetae broad, spatulate Potamothrix bavaricus (Figures 15 & 16)

\- Spermathecal chaetae long, narrow Antipodrilus - 11

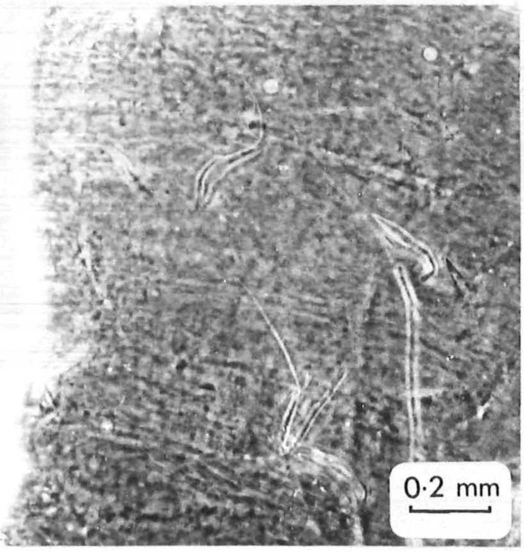

FIGURE 15

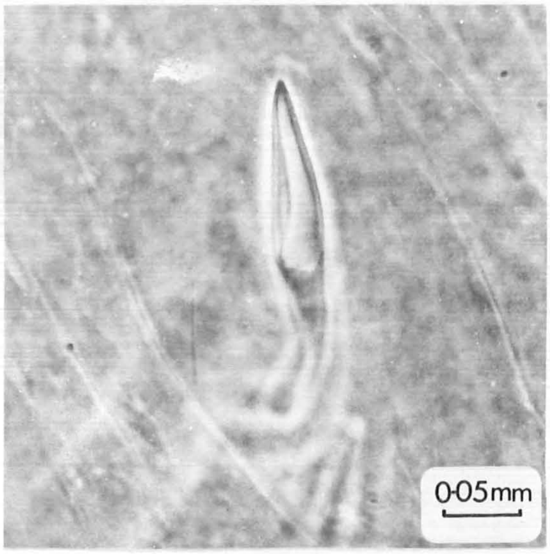

FIGURE 16

11. Anterior ventral chaetae with upper tooth as thick as but much longer than the lower A.timmsi

\- Anterior ventral chaetae with upper tooth a little longer and thinner than the lower A. davidis

12. Anterior chaetae bifid, posterior chaetae pectinate Telmatodrilus pectinatus

\- All chaetae bifid, or a few simple pointed, none pectinate.. 13

13. Chaetae with upper tooth shorter and thinner than the lower (endemic to Macquarie Island) Macquaridrilus benettae

- Chaetae with upper tooth as long as or longer than lower (cosmopolitan species)................. 14

14. Some posterior chaetae simple pointed. Prostates diffuse. Coelomocytes present. No cuticular penis sheaths (marine) *Monopylephorus rubroniveus*

- No simple pointed chaetae. Prostates compact. Coelomocytes absent. Cuticular penis sheaths present in mature specimens *Limnodrilus* 15
(Figures 17 & 18)

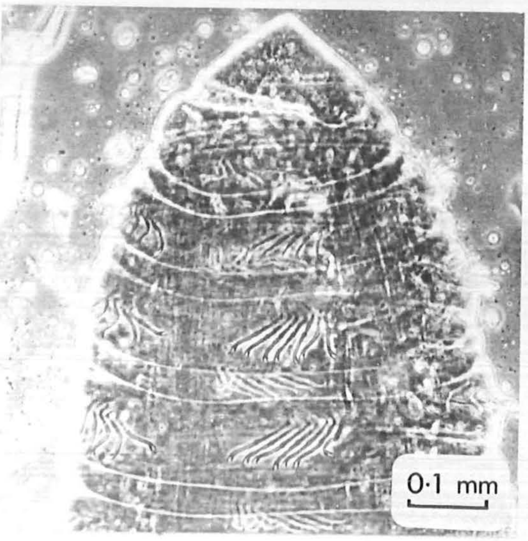

FIGURE 17

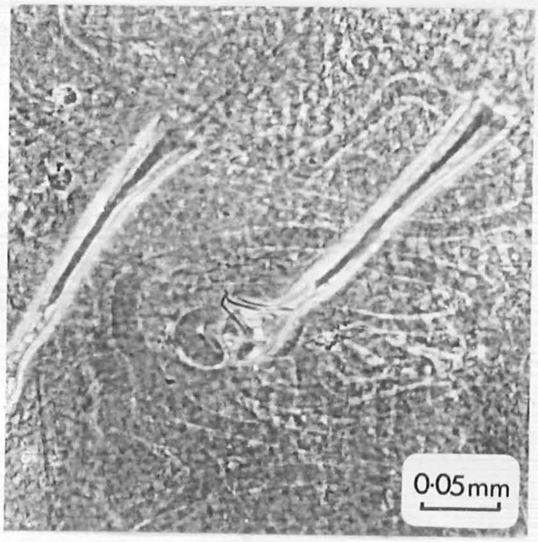

FIGURE 18

15. Upper tooth of anterior chaetae thick and much longer than the lower. Penis sheaths mostly 1-4 times longer than broad *L. udekemianus*
(Figure 19)

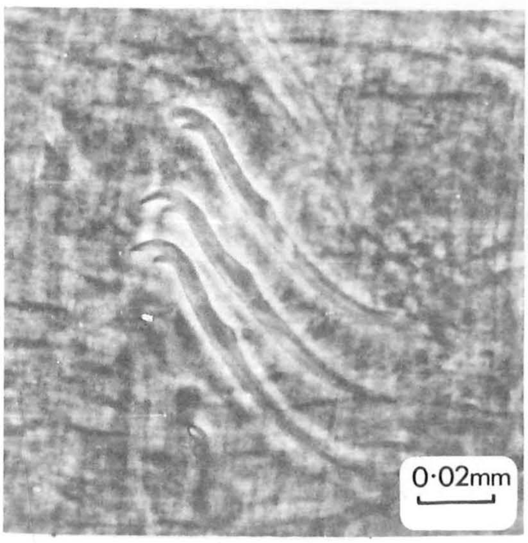

FIGURE 19

\- Upper teeth as long as, or longer than lower, usually thinner than lower. Penis sheaths more than 4 times longer than broad.................. 16

16\. Penis sheaths up to 14 times longer than broad (the commonest tubificid anywhere).

L. hoffmeisteri
(Figures 17 & 18)

\- Penis sheaths up to 43 times longer than broad

L. claparedeianus

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